10th International Conference on

Luminescent Detectors and Transformers of Ionizing Radiation

Book of Abstracts

CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

Fyzikální ústav
Akademie věd ČR, v. v. i.

9-14 September 2018, Prague, Czech Republic

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Organized by

- Fyzikální ústav Akademie věd ČR, v. v. i. **Institute of Physics of the Czech Academy of Sciences**
- CTU CZECH TECHNICAL UNIVERSITY IN PRAGUE **Faculty of Nuclear Sciences and Physical Engineering Czech Technical University in Prague**

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- **CRYTUR** spol. s r.o., Turnov, Czech Republic
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- **C&A Corporation**, Japan

Conference chairpersons:
Martin Nikl (Institute of Physics of the Czech Academy of Sciences, Prague)
Tomáš Trojek (Faculty of Nuclear Sciences and Physical Engineering CTU in Prague)

Topics

- Radioluminescence and scintillation mechanisms, energy transfer and storage, optically and thermally stimulated luminescence in solids (RL&SM-ET&S-TSL&OSL)
- Physics and chemistry of luminescent materials for detectors and transformers of ionizing radiation, technology and preparation methods (PChLM&Techn)
- Defects and their role in material performance (Def&Perfor)
- Novel phenomena, energy transfer and storage in restricted geometries, Nanophosphors, and nanocomposites (Novel&Nano)
- New detector concepts and novel instrumentation (NDET&Instr)
- Application of scintillators and transformers of ionizing radiation for medical diagnostics, biological research and environmental studies (Appl-Sci&T-Med-Bi-Env)
- Application of luminescence materials in dosimetry of ionizing radiation including medical dosimetry, ion and cosmic ray dosimetry, and homeland security dosimetry (Appl-LM-Dosim)
- Emergency dosimetry (Emerg-Dosim)

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Preface

The Institute of Physics of the Czech Academy of Sciences and Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, invite you to the 10th European Conference on Luminescent Detectors and Transformers of Ionising Radiation to be held in Prague, September 9-14, 2018. LUMDETR2018 will continue the tradition established by the previous meetings in Latvia (Riga, 1991), Estonia (Tallin, 1994), Poland (Ustron, 1997), Latvia (Riga, 2000), Czech Republic (Prague, 2003), Ukraine (Lviv, 2006), Poland (Krakow, 2009), Germany (Halle, 2012), Estonia (Tartu, 2015). This conference provides an interdisciplinary forum for the presentation of the latest developments in basic and applied research in the field of radioluminescence, the processes of energy transfer and storage in solid state systems, the physics and chemistry of luminescent phosphor and scintillation materials, and related applications.

More than 220 colleagues from 32 countries have registered at the web site of the conference which evidences high interest of the community in LUMDETR conference. Thirteen invited lectures will be given by leading scientists to introduce the main topics and Sessions of the conference. The body of the conference program consists of 63 oral and 142 poster presentations following all the topics. Delivered manuscripts will be refereed and the accepted ones will be published traditionally in the journal Radiation Measurements (Elsevier Publ. House). Organization committee did its best to prepare for all of you a comfortable stay in Prague and we sincerely hope that you will enjoy not only the conference program, but also all the beauty of historical Prague.

Our big thanks are also directed to the conference sponsors: EC H2020 project ASCIMAT and companies CRYTUR spol. s r.o. and Nuvia a.s. from Czech republic and C&A Co. from Japan.

We want to thank to all of you for coming and wish you a pleasant stay in Prague and Czech Republic.

On behalf of the Organization committee

Martin Nikl and Tomáš Trojek
Conference chairpersons

Contents

Abstracts are sorted according to the program.

Important Information

Contact address

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Emergency phone numbers (free calls):

Police: 158
Ambulance: 155
Fire Department: 150
Unified Emergency Call: 112

Conference site

The LumDeTr2018 conference will take place at the following site:

Faculty of Nuclear Sciences and Physical Engineering
Czech Technical University in Prague
Břehová 7, Prague 1

The conference site is suitably located downtown, 10 minutes from the city center at the Vltava river bank with public transport (tram, underground) within 1-5 minutes walking distance. Accommodation will be provided in comfortable modern student colleges easily reached by the public transport (20-30 min from the conference site) or in selected hotels downtown close to the conference site.

In September there is an intense tourist season in Prague with a rich offering of various cultural events. The weather is generally quite pleasant (day temperatures 20-25 ^{o}C).

Program

Sunday, 9 September 2018

16:00 – 18:00 Registration

Location: Conference site

18:00 – 20:00 Welcome Party

Location: Conference site

Monday, 10 September 2018

09:00 – 09:20 Conference opening

Location: Lecture Hall

09:20 – 10:50 Session 1 - RL&SM-ET&S-TSL&OSL I.

Location: Lecture Hall

09:20 – 09:50	Christophe Dujardin:	*Charge effects in semiconductor nanocrystals under ionizing radiation*
09:50 – 10:05	Sergey I. Omelkov:	*The influence of band structure on the hot intraband luminescence*
10:05 – 10:20	Gintautas Tamulaitis:	*Timing properties of GAGG:Ce and LSO:Ce scintillators with and without codoping*
10:20 – 10:35	Mauro Fasoli:	*Optically stimulated luminescence in RE-doped LuAG crystals*
10:35 – 10:50	Vasilii Khanin:	*Afterglow curves modeling from TSL measurements for complex garnets*

10:50 – 11:20 Coffee break, Poster I installation

11:20 – 13:05 Session 2 – Appl-LM-Dosim I.

Location: Lecture Hall

11:20 – 11:50	Eduardo Gardenali Yukihara:	*A Review of Recent Material Developments for Optically Stimulated Luminescence Applications*
11:50 – 12:05	Massimo Piccinini:	*Visible photoluminescence of color centers in LiF crystals for advanced diagnostics of 18 – 27 MeV proton beams*
12:05 – 12:20	Lucie Fiserova:	*Thermal neutron detection using lanthanide oxybromides*
12:20 – 12:35	Francesca Cova:	*Dual response of RE-doped sol-gel silica fibers to high energy electrons*
12:35 – 12:50	Dagmara Kulesza:	Lu_2O_3*:Tb, M (M=Hf, Ti, Nb) Storage Phosphors: Dose-Response Dependence, Radiation Hardness and Self-Dose Effect*

12:50 – 13:05	Anne-Laure Bulin:	*Nanoscintillators to improve radiation therapy outcomes: dose enhancement effect induced in 3D models of glioblastoma upon synchrotron radiation*

13:05 – 14:30 Lunch break, Poster I installation

14:30 – 16:15

Session 3 – Novel&Nano

Location: Lecture Hall

14:30 – 15:00	Václav Čuba:	*Inorganic nanoscintillators with ultrafast decay: a comparison and different synthesis strategies*
15:00 – 15:15	Anna Vedda:	*The ESQUIRE project: Quantum Dots for scintillation detectors*
15:15 – 15:30	Alice Hospodková:	*InGaN/GaN MQW scintillator - design and applications*
15:30 – 15:45	Anatoliy Voloshinovskii:	*Nanocomposite polymer scintillator materials*
15:45 – 16:00	Eva Mihóková:	*Novel scintillating nanocomposites for X-ray induced photodynamic therapy*
16:00 – 16:15	Fabrizio Davì:	*Decay time and residual stress in scintillators: a continuum mechanics approach.*

16:15 – 18:00

Poster session I with refreshment (Novel&Nano, Appl-LM-Dosim, RL&SM-ET&S-TSL&OSL)

Location: Poster area

Tuesday, 11 September 2018

09:00 – 10:45 Session 4 – Def&Perfor

Location: Lecture Hall

09:00 – 09:30	Aleksandr Lushchik:	*Radiation-Induced Structural Defects and Their Thermal Annealing in Magnesium Aluminate Spinel*
09:30 – 09:45	Sergiu Vasile Nistor:	*About the nature and distribution of defects in crystalline cubic boron nitride wide band-gap semiconductor*
09:45 – 10:00	Evgeny Radzhabov:	*Electron transfer between heterogeneous lanthanides in BaF_2 crystals*
10:00 – 10:15	Mariusz Kłosowski:	*Spectral analysis of LiF:Mg,Cu,P detectors with different dopants concentration after ultra-high radiation doses*
10:15 – 10:30	Serge Nagorny:	*Anomalous Quenching Factor for alpha particles in ZnSe crystals – is puzzle solved?*
10:30 – 10:45	Alexander Surdo:	*Non-radiation creation of complex centers in wide-gap oxide crystals*

10:45 – 11:15 Coffee break, removal of Poster I

11:15 – 13:00 Session 5 – PChLM&Techn

Location: Lecture Hall

11:15 – 11:45	Akira Yoshikawa:	*New approach for the growth of scintillator crystals*
11:45 – 12:00	Vladimir Ouspenski:	*Engineering of Scintillation Materials and complex phases crystals synthesis*
12:00 – 12:15	Yuui Yokota:	*Scintillation Properties of Eu-doped $LiCaAlF_6$ and $LiSrAlF_6$ fluoride single crystals with improved Eu segregation*
12:15 – 12:30	Jeppe Brage Christensen:	*Applications of amorphous track structure models for correction of ionization quenching in organic scintillators exposed to ion beams*
12:30 – 12:45	Shohei Kodama:	*Development of red-orange-emitting halide scintillator for single photon counting*

12:45	–	13:00	Zewang Hu:	*Fabrication and performance optimization of Pr:Lu3Al5O12 ceramic scintillators*
13:00	–	14:30	Lunch break, Poster II installation	

14:30 – 16:15

Session 6 – Appl-Sci&T-Med-Bi-Env

Location: Lecture Hall

14:30	–	15:00	Claus E. Andersen:	*Latest trends in medical dosimetry using fiber-optic luminescent instrumentation*
15:00	–	15:15	Andrea Polesel:	*Development of a PET module with DOI and timing capabilities*
15:15	–	15:30	Shunsuke Kurosawa:	*Scintillation Properties of Y-admixed* $Gd_2Si_2O_7$ *doped with Ce*
15:30	–	15:45	Vítězslav Jarý:	Eu^{2+}*-doped* $ARES_2$ *sulfides – novel multifunctional optical materials*
15:45	–	16:00	Hong Joo Kim:	*Luminescence and scintillation characterization of PbMoO4 scintillation crystal for neutrinoless double beta decay search*
16:00	–	16:15	Georgy Dosovitskiy:	*Ceramic scintillators with potential for neutron detection*

16:15 – 18:00

Poster session II with refreshment (Appl-Sci&T-Med-Bi-Env, Def&Perfor, PChLM&Techn)

Location: Poster area

19:00 – 20:30

Concert in Bethlehem Chapel

Location: Bethlehem square (Betlemske namesti)

Wednesday, 12 September 2018

09:00 – 10:45 Session 7 – NDET&Instr

Location: Lecture Hall

09:00	–	09:30	Etiennette Auffray:	*Fast scintillators for high energy physics and medical applications*
09:30	–	09:45	Mark Akselrod:	*Latest advances in aluminum oxide OSL materials and instrumentation*
09:45	–	10:00	Paweł Bilski:	*Fluorescent imaging of heavy charged particle tracks with LiF single crystals*
10:00	–	10:15	Nicolò Borghi:	*Characterization of scintillators and optical components for the ESS Target Imaging System*
10:15	–	10:30	Rosalinde Pots:	*Improving light collection of scintillating crystals using photonic crystals*
10:30	–	10:45	Yuriy Zorenko:	*Recent progress in the development of composite scintillators based on the single crystalline films of garnet compounds*

10:45 – 11:15 Coffee break

11:15 – 12:45 Session 8 – RL&SM-ET&S-TSL&OSL II.

Location: Lecture Hall

11:15	–	11:45	Andrey Vasil'ev:	*Evolution of track structure and its influence on scintillation characteristics: decay profile, non-proportionality and energy resolution*
11:45	–	12:00	Andrei Belsky:	*Time-resolved lumenescence z-scan using power fs laser pulses*
12:00	–	12:15	Pavlo Arhipov:	*Features of YAG and YAG:Ce scintillation crystals grown under CO-containing atmosphere*
12:15	–	12:30	Karol Bartosiewicz:	*The Ce and Li concentration ratio influence on the scintillation and luminescence features in* $Gd_3Ga_3Al_2O_{12}$ *single crystals*
12:30	–	12:45	Maksym Buryi:	*Charge trapping and energy transfer in* $Y(Lu)_3Al_5O_{12}$*:Eu,(Fe) ceramics: EPR and TSL study*

12:50 – 13:30 **Buffet Lunches**

Location: Conference site

13:30 – 22:00 **Conference trip with excursion**

Location: Plzen, Pilsen Urquell Brewery and Brewery Museum . Start from conference site

19:00 – 21:00 **Conference Dinner**

Location: Plzen, restaurant Spilka in the area of Pilsen Urquell Brewery

Thursday, 13 September 2018

09:00 – 10:45 **Session 9 – NDET&Instr II.**

Location: Lecture Hall

09:00 – 09:30	E. Zych:	*Pr^{3+} luminescence for wide-range thermometry*
09:30 – 09:45	Steffen Greilich:	*Particle Detection Efficiency of Fluorescent Nuclear Track Detectors in Various Clinical Ion Beams*
09:45 – 10:00	Vladimir Pankratov:	*Luminescence spectroscopy under synchrotron radiation: from SUPERLUMI to FINESTLUMI*
10:00 – 10:15	Li-Yen Chen:	*Development and verification of a new OSL-ring dosimeter system*
10:15 – 10:30	Oleksandr Sobolev:	*Hierarchical clustering of CsI(Tl) scintillation detector pulses*
10:30 – 10:45	Quoc Vuong Phan:	*Pulse shape discrimination study with new Tl_2ZrCl_6 crystal scintillator*

10:45 – 11:15 Coffee break, Poster II removal

11:15 – 13:00 **Session 10 – RL&SM-ET&S-TSL&OSL III.**

Location: Lecture Hall

11:15 – 11:45	Edith Bourret:	*Investigations of halide scintillators at the atomic and micro scale*
11:45 – 12:00	Reuven Chen:	*Thermoluminescence governed by the Auger-recombination process*
12:00 – 12:15	Winicjusz Drozdowski:	*β-Ga_2O_3:Ce as a Fast Scintillator: a Doubtful Role of Cerium*
12:15 – 12:30	Marek Grinberg:	*Normal and anomalous luminescence in SrS:0.05%Ce^{3+} under high hydrostatic pressure*
12:30 – 12:45	Miroslav Kucera:	*Growth and scintillation properties of Ce^{3+}-doped thin film garnet and perovskite scintillators*
12:45 – 13:00	Kyoung Jin Kim:	*Effects of nonstoichiometric composition on luminescence and scintillation properties of Ce doped $Gd_3Al_2Ga_3O_{12}$ single crystals*

13:00 – 14:30	Lunch break, Poster III installation	
14:30 – 16:15	**Session 11 – Appl-LM-Dosim II** *Location: Lecture Hall*	
14:30 – 15:00	Marijke De Saint-Hubert:	*Fluorescent nuclear track detectors (FNTDs) to model RBE in proton therapy: correlation to microdosimetric quantities and biological observations*
15:00 – 15:15	Adrie J.J. Bos:	*Experimental Alpha Particle Microdosimetry using Fluorescent Nuclear Track Detectors*
15:15 – 15:30	Antoine Zink:	*LM-OSL investigations of X-rays irradiation on terracotta*
15:30 – 15:45	Hui-Yu Tsai:	*Clinical Application of Ionization Density Dependence of the Glow Curve Characteristics for Linear Energy Transfer (LET) Measurements in Therapeutic Proton Beams*
15:45 – 16:00	Ilan Eliyahu:	*Are there dose-rate effects in the thermoluminiscence of LiF:Mg,Ti (HARSHAW)?*
16:00 – 16:15	Siritorn Buranurak:	*Statistical-based modeling and nanoDot OSL dosimetry for evaluation of potential factors contributing to radiation-induced skin injury during Transarterial Chemoembolization*
16:15 – 18:00	**Poster session III with refreshment (RL&SM-ET&S-TSL&OSL, PChLM&Techn, NDET&Instr, Emerg-Dosim)**	

Friday, 14 September 2018

09:00 – 11:00 **Session 12 – RL&SM-ET&S-TSL&OSL IV**

Location: Lecture Hall

09:00 – 09:30	Mikhail G Brik:	*First-principles calculations of optical properties of scintillating materials*
09:30 – 09:45	Arkadiusz Mandowski:	*Bi-localized recombination*
09:45 – 10:00	Vitali Nagirnyi:	*Energy transfer processes upon thermal quenching of self-trapped excitons in* $CdWO_4$*:Sm crystals*
10:00 – 10:15	Petr Průša:	*Thermoluminescence of LuAG:Ce,Mg epitaxial films*
10:15 – 10:30	Natalia Yu. Vereschagina:	*TSL and OSL kinetics with impeded transport of charge carriers*
10:30 – 10:45	Ivan Venevtsev:	*Correlation between TSL and temperature behavior of the X-ray excited luminescence below room temperature in cerium doped garnets*
10:45 – 11:00	Makaiko L Chithambo:	*Thermal effects on stimulated luminescence of* $SrAl_2O_4:Eu^{2+},Dy^{3+}$ *and* $Sr_4Al_{14}O_{25}:Eu^{2+}, Dy^{3+}$*: Thermal assistance and thermal quenching*

11:00 – 11:30 Coffee break, Poster III removal

11:30 – 13:00 **Session 13 – Emerg-Dosim**

Location: Lecture Hall

11:30 – 12:00	Sergey Sholom:	*Emergency Luminescent Dosimetry using modern smartphones*
12:00 – 12:15	Céline Bassinet:	*Investigation of luminescence signal properties from common salts (NaCl) and salted snacks for radiation accident dosimetry*
12:15 – 12:30	Stephen W.S. McKeever:	*Observations regarding the Build-Up Effect in Radiophotoluminescence of Silver-Doped Phosphate Glasses*
12:30 – 12:45	Xiaopu Chen:	*Fabrication and performance optimization of Mg^{2+} codoped Ce:Lu$_3$Al$_5$O$_{12}$ scintillation ceramics*
12:45 – 13:00	Ioanna K. Sfampa:	*TL measurements of in-vitro and in-vivo aged feldspathic porcelain*

13:00 – 13:30 Conference summary and closing

Location: Lecture Hall

Abstracts

Charge effects in semiconductor nanocrystals under ionizing radiation

Benoit Mahler[1], Justine Baronnier[1], Yusong Gan[1], Julien Houel[1], Andrey Vasil'ev[2], and
Christophe Dujardin[1]

[1]*ILM-University Lyon 1, 10 rue Ada Byron, Villeurbanne, France*
[2]*The Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Russia*

Nanoparticle of direct band-gap semiconductors (Q-dots) have attracted a lot of interest for their luminescence properties in the last decades. Their scintillating properties have been first presented in 2006 by Letant et. al [1]. Among potential uses such as photodynamic therapy under penetrating x-rays nanoscintillators may address the needs for fast timing. As an illustration, lateral confinement effect can speed up the emission [2] and recent works have demonstrated fast response below 1 ns of semiconductor nanoplatelets under x-rays [3].

One of the limitations is probably the weak energy deposition efficiency, particularly in the case of diluted media such as demonstrated by Bulin et. al. [4]. Based on this energy distribution among nanoparticles, the fraction of deposited electrons and holes is expected to be different from particle to particle resulting in potential charge effects. Charge effects in semiconductors are known to lead to specific spectroscopic behaviors such as blinking, through formation of trions and bi-excitons.

In this contribution, we present the obtained recent results regarding the charge effects on various semiconductor nanocrystals: Q-dots, spherical quantum wells and nanoplatelets. Comparison of their spectroscopic properties under resonant and ionizing radiation is presented and numerical simulations on the charge deposition are discussed.

[1] S. E. Létant and T.-F. Wang, Nano Letters, vol. 6, no. 12, pp. 2877–2880, 2006.

[2] A. W. Achtstein et. al., Physical Review Letters, vol. 116, no. 11, p. 116802, 2016.

[3] R. Turtos et. al. Journal of Instrumentation, vol. 11, no. 10, pp. P10 015–P10 015, 2016.

[4] A.-L. Bulin et. al. Nanoscale, vol. 7, no. 13, pp. 5744–5751, 2015.

The influence of band structure on the hot intraband luminescence

Sergey I. Omelkov, Vitali Nagirnyi, and Marco Kirm

Institute of Physics, University of Tartu, W. Ostwaldi 1, Tartu 50411, Estonia

Recent progress in various fields of scintillator applications has created a high demand for fast scintillators. In particular, the Time-Of-Flight Positron Emission Tomography (TOF-PET) technique requires coincidence time resolutions (CTRs) of 10 ps potentially allowing direct imaging without reconstruction. High luminosity storage rings also demand improving the timing capabilities of calorimeters down to 10 ps to distinguish several events per bunch crossing. Conventional rare-earth-doped scintillators are unable to provide such time resolution without the aid of so-called prompt photons, which are emitted within picoseconds after interaction with gamma-quantum [1].

Hot intraband luminescence (IBL) is a candidate for providing at least some of those prompt photons. IBL is a low yield emission connected with the radiative transitions of hot electrons or hot holes between the states of the conduction or valence band of a crystal, respectively. The continuous spectrum of IBL covers the whole transparency region of a material [2]. The decay time of IBL is expected to be below 1 ps, but the highest scintillation light yield (LY) measured so far is only about 33 ph/MeV [2]. In binary materials, the yield of IBL has shown an inverse correlation with material phonon energies [2], however for complex compounds other factors can be more important. Understanding those factors can help predict and control the IBL yield in scintillators.

We report the influence of the electronic band structure on the yield and spectrum of IBL. We show that forbidden gaps with zero density of states in the valence band are manifested in the IBL spectrum as “steps” at certain photon energies, which roughly correspond to the onset of possible transitions between the sub-bands. In this case, the total IBL yield can be higher than in similar material without valence band splitting. Such transitions fundamentally differ from crossluminescence [3], because in the latter case the lower sub-band is a localized core level which yields different transition probabilities and much longer decay times ($\sim$1 ns). We present the comparison of band structures and IBL features in various complex materials, such as rare-earth oxyfluorides, rare-earth arsenates, alkali-earth tungstates, molybdates and other materials.

[1] S. Gundacker et al., J. Instrum. 11 (2016) P08008

[2] S. I. Omelkov et al., J. Lumin. 198 (2018) 260.

[3] V.N. Makhov, Phys. Scr. 89 (2014) 044010

Timing properties of GAGG:Ce and LSO:Ce scintillators with and without codoping

Gintautas Tamulaitis[1], Saulius Nargelas[1], Augustas Vaitkevičius[1], Etiennette Auffray[2], Marco Toliman Lucchini[3], Alberto Gola[3], Alberto Mazzi[3], Claudio Piemonte[3], Mikhail Korjik[4], Andrey Fedorov[4], Vitaly Mechinsky[4], and Oleg Sidletsky[5]

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[2]*CERN, CH-1211 Geneve 23, Switzerland*
[3]*Fundazione Bruno Kessler, 18 Via Sommarive, 38213, Povo, Trento, Italy*
[4]*Belarus State University, 11 Bobruiskaya str., 220030, Minsk, Belarus*
[5]*Institute of Scintillation Materials of National Academy of Science of Ukraine, 60 Lenina Av., 61001, Kharkiv, Ukraine*

Fast response to short-pulse excitation becomes the key property of scintillators for radiation detectors to be used in future high-luminosity collider experiments at CERN and other large high-energy physics infrastructures and medical imaging applications. We report on the study of excitation transfer and formation of the front-edge of luminescence response in oxyorthosilicates LSO:Ce and garnets GAGG:Ce with different codoping The study was performed by using optical pump and probe technique and time resolved photo-luminescence in subpicosecond domain. Tuneable wavelength of the pump pulses enabled resonant excitation of different structural units in the crystal, while a wide spectrum of the white-light continuum exploited for probing ensured spectrally resolved detection of free and localized nonequilibrium carriers. The data obtained at optical excitation were compared with the data acquired in our coincidence resolving timing experiments performed at different temperatures on the same samples using a Na-22 source.

Our study of free carrier absorption at different excitation photon energies and the comparison of the excitation transfer in undoped GAGG revealed that the luminescence response time of GAGG:Ce to short-pulse excitation is determined by carrier trapping. Codoping of GAGG:Ce and LSO:Ce with divalent ions allows for faster resonant electron transfer to cerium ions at an acceptable decrease of the light yield in GAGG:Ce,Mg and without a considerable decrease in LSO:Ce,Ca. Codoping by Mg suppresses the temperature dependence of CRT, which is observed in uncodoped GAGG:Ce. The introduction of yttrium into LSO matrix does not significantly affect either the light yield or response time, though trapping of nonequilibrium electrons in LYSO:Ce is stronger than that in LSO:Ce. Figures of merits for evaluation of the timing properties of the scintillators based on LSO and GAGG are suggested.

Optically stimulated luminescence in RE-doped LuAG crystals

Mauro Fasoli[1], Salvatore Gallo[2], Ivan Veronese[2], and Anna Vedda[1]

[1]*Università di Milano Bicocca, Dipartimento di Scienza dei Materiali, via Cozzi 55, 20125 Milano, Italy*

[2]*Università degli Studi di Milano, Dipartimento di Fisica and INFN, via Celoria 16, 20133 Milano, Italy*

Optically stimulated luminescence (OSL) technique is being extensively employed to assess the delivered dose in different applications, in particular dating and dosimetry. The dating of geological sediments, for example, relies on the luminescence properties of quartz and feldspars. Over the geological era, the exposure of buried quartz grains to natural radioactivity results in charges trapped in localized defects. Since some of these trapped electrons can be released by exposure to blue light producing an UV emission, it is possible to estimate the dose delivered to the sample (and the time elapsed) since its last exposure to sunlight (i.e. the burial time) using the OSL technique [1]. The same physical process is also exploited in radiation dosimetry applications using synthetic crystals commercially available (e.g. Al_2O_3:C) [2] and has been proposed for real time dose measurements when coupled to radioluminescence (RL) signal [3].

In this work, we describe the recently discovered OSL properties of rare earth doped $Lu_3Al_5O_{12}$ crystals (LuAG:RE). We found, in fact, that a trap responsible for an intense peak detected with thermally stimulated luminescence (TSL), can be significantly depleted by exposure to white light. We will present a detailed characterization of OSL in LuAG showing the experimental evidences of the phenomenon. We investigated its properties to evaluate the feasibility of using this material as a dosimeter for various applications. In particular, we determined the trap parameters of the optically bleachable defect, its bleaching efficiency as a function of stimulation wavelength, the OSL emission spectrum, etc. Several samples with different growing conditions (RE-doping, co-doping, post growth annealing, etc.) have been considered. Moreover, our investigation aimed at the identification of the point defect responsible for the dosimetric traps. This would possibly allow the engineering of the material resulting in improved performances of the dosimeter. The state of the art of our investigation will be presented.

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Afterglow curves modeling from TSL measurements for complex garnets

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Afterglow is an important phenomenon in luminescent materials and can be desired (e.g. persistent phosphors) or undesired (e.g. scintillators). Understanding and predicting afterglow is often based on determination of kinetic trap parameters (thermal trap depth, frequency factor and kinetic order) via analysis of thermally stimulated luminescence (TSL) glow curves. The most used approaches for processing of the TSL data are first [1] or second [2] kinetic order one trap one recombination center (OTOR) models and interactive kinetics [3] models for traps with discrete energy levels.

Here we present an approach for the description of the time-dependent afterglow from TSL glow curves using a rigorous model with a distribution of trap depths. The method is based on the deconvolution of the energy dependent density of occupied traps derived from TSL glow curves using Tikhonov regularization [4].

The objects used to test the validity of this new approach are mixed garnet $Gd_3Ga_3Al_2O_{12}$:Ce ceramic scintillators. The samples have been left nominally pure or co-doped with 25 ppm of Yb^{3+} or Eu^{3+} ions, known [5] to create efficient electron traps.

The work is organized in the following manner: we first describe experimental evidence of correlation between TSL and afterglow curves and provide evidence for the existence of trap depth distribution through thermal cleaning experiments and the dependence of afterglow curve on irradiation conditions and time. Then we present the mathematical approach for analysis of afterglow using standard (discrete trap depth) TSL models and our new method. Finally, we analyze the results by comparing simulated afterglow behavior based on the different models to experimental data for complex garnets and discuss the applicability/limitations of this approach for other scintillator systems.

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A Review of Recent Material Developments for Optically Stimulated Luminescence Applications

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The Optically Stimulated Luminescence (OSL) technique has been used commercially for personal dosimetry [1, 2] and digital radiography [3] for more than 20 years. These two fields have developed relatively separately, with emphasis in materials with very different properties. Al_2O_3:C [4] and BeO [5, 6] have been used as OSL dosimeters, having high sensitivity to ionizing radiation and low effective atomic number, whereas high Z materials such as BaFBr:Eu^{2+}have been used as photostimulable phosphors [7]. Curiously these two fields (dosimetry and imaging) only recently started to converge in the field of 2D dosimetry [8], but the lack of suitable OSL materials remains one of the main obstacles to develop precise 2D dosimeters based on the OSL technology. Particularly compared to the field of thermoluminescence (TL) dosimetry, the availability of OSL materials for dosimetry remains severely limited even in personal dosimetry.

In this talk we will review recent material developments for OSL applications in personal dosimetry, medical dosimetry, and biomedical imaging. We will highlight major advances in material developments and limitations of these new materials. We will also discuss new applications and concepts, and some of the existing obstacles that have not yet been surmounted. The goal is to provide a basic overview to help a more focused material research, hopefully contributing to the advancement of the field.

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Visible photoluminescence of color centers in LiF crystals for advanced diagnostics of 18 – 27 MeV proton beams

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Solid-state radiation detectors based on the visible photoluminescence of F_2 and $F_3{}^+$ color centers in lithium fluoride (LiF) [1] crystals have been used for characterizing proton beams, in the energy range of 18-27 MeV, produced by the TOP-IMPLART linear accelerator, under development for protontherapy applications at ENEA C.R. Frascati, Italy. Visible fluorescence microscopy was successfully used to read the latent proton beam images stored in the LiF crystals, thanks to high emission efficiency of F_2 and $F_3{}^+$ color centers obtained by simultaneous optical excitation in the blue spectral range [2]. The high intrinsic spatial resolution and wide dynamic range of these novel LiF detectors allow obtaining two-dimensional images of both the beam transverse intensity distribution and of the Bragg curve. The Bragg peak position was identified with micrometric precision, even in the case of beams with different energy components at both high ($2\text{x}10^{13}$ H^+/cm^2) and low fluence ($2\text{x}10^{10}$ H^+/cm^2). Photoluminescence spectra of 25 MeV proton-irradiated LiF crystals, measured under blue laser excitation, show a linear behavior vs fluence (from $5\text{x}10^8$ to $7\text{x}10^9$ H^+/cm^2) and are promising for dose estimation in clinical dosimetry and protontherapy.

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Thermal neutron detection using lanthanide oxybromides

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The work presents selected lanthanide oxybromides such as GdOBr:Ce, LaOBr:Ce, YOBr:Ce, EuOBr:Ce and LuOBr:Ce as a potential thermal neutron detection compounds in connection with Li-6 isotope. The oxybromides were prepared by solid-state synthesis and the crystallinity of compounds was determined by X-ray powder diffraction analysis. Subsequently, the study of radioluminescence spectra was performed to compare the light intensity of each compound. Furthermore, since the primary purpose is to detect charged particles, e.g. alpha and triton, the sensitivity of the compounds to alpha radiation was determined. In connection with fast decay time, high light yield and simple production it is possible to consider this group of scintillation phosphors as a potential substitute of ZnS:Ag in thermal neutron detection systems, to which all measured characteristics were compared to.

Dual response of RE-doped sol-gel silica fibers to high energy electrons

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Rare-earth doped sol-gel glasses were proven to be suitable materials for scintillating optical fiber sensors [1], to be employed in real-time medical dosimetry [2]. To exploit the high granularity and flexibility of calorimeters made of fibers, their use as the active scintillating material in a sampling electromagnetic Spaghetti Calorimeter (SpaCal) [3] or as the scintillating component in a dual-readout calorimeter [4], coupled with undoped fibers acting as Cherenkov radiators, has also been recently proposed. Besides crystalline fibers, active research on silica fibers is also being carried on. An extremely good radiation hardness is a crucial property for high-energy physics applications: previous results of irradiation tests on Ce-doped silica fibers with X- and γ-rays up to 10 kGy pointed out the formation of radiation-induced defects, however an improvement of radiation resistance by reducing Ce content inside the fiber core was achieved [5], paving the way for further material development.

Here we present an in depth characterization of Ce-doped sol-gel silica fibers under GeV electron beam exposure: silica fibers were tested in a SpaCal prototype and the analysis of their response suggests the possibility of a dual readout of Cherenkov and scintillation light simultaneously with the same doped silica fiber. An event by event pulse shape-based discrimination of Cherenkov and scintillation signals permits a separate study of linearity as a function of energy and attenuation length, taking advantage of the double side readout technique [4, 5]. The investigation of various mechanisms of interaction between radiation and sol-gel silica fibers as well as of their scintillation properties represents the goal of this work. An accurate comparison with their photoluminescence and radioluminescence response has been carried out, in order to optimize silica fibers performances as both scintillators and Cherenkov radiators.

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Lu_2O_3:Tb, M (M=Hf, Ti, Nb) Storage Phosphors: Dose-Response Dependence, Radiation Hardness and Self-Dose Effect

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Thermoluminescent properties and energy storage characteristics of Lu_2O_3:Tb,M (M= Hf, Ti, Nb) sintered ceramics induced by ionizing radiation will be presented and discussed. The main interest will be given to the dose-response dependence, radiation hardness and fading of the storage phosphors. An exceptionally wide linearity of the dose response of Lu_2O_3:Tb,Hf will be proved. Remarkably high hardness of all the compositions will be presented - after a dose of 1 kGy no change in response to small doses is observed. The ceramics show significant different fading behavior. The Tb,Ti material whose TL peaks at 320 °C experiences higher fading than Tb,Hf ceramics which has TL at 220 °C. Also the effect of self-dose due to the presence of ^{176}Lu will be presented.

Nanoscintillators to improve radiation therapy outcomes: dose enhancement effect induced in 3D models of glioblastoma upon synchrotron radiation

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Radiation therapy remains one of the more widely used cancer treatment, as it comprises the standard of care for more than 50% of cancer patients. However, this therapeutic modality remains limited by an intrinsic toxicity caused by a lack of contrast between the dose deposited in the cancer tissue and the dose deposited in the surrounding healthy tissue.

This limitation has particular relevance to glioblastoma, one of the most common types of brain cancers in adults. Radiation therapy for glioblastoma is challenged by the presence of sensitive surrounding tissues, which strongly limits the radiation doses that can safely be delivered. Consequently, glioblastoma has a dismal prognosis: the median survival is approximately one year, despite the current standard of care.

To improve the efficacy of radiation therapy, scintillating nanoparticles are emerging as promising therapeutic agents. These nanoscintillators can act as both contrast enhancers for radiation therapy, while also functioning as a local light source to enable deep tissue photodynamic therapy to induce an additional, localized cytotoxic effect.

To investigate this innovative concept in a physicochemical and biomedical context, we explore the use of LaF_3 and LaF_3:Ce nanoparticles to achieve radiation dose enhancement in 3D models of glioblastoma using monochromatic synchrotron radiation.

Inorganic nanoscintillators with ultrafast decay: a comparison and different synthesis strategies

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Various nanosized scintillating materials, prospective for the manufacture of time of flight PET detectors, have been currently investigated. Those based on ZnO:Ga(La), $CsPbX_3$ (X = Cl, Br, I) and CdSe seem to be among the most promising nanoscintillating compounds. Due to their shape and size controllable luminescence, all of them can be tailored to feature subnanosecond photoluminescence decay.

While ZnO:Ga(La) offers probably the best timing properties [1] and luminescence tunable via tailored ZnCd(Mg)O:Ga compounds, the wurtzite crystalline structure and rather low yield present serious disadvantages. $CsPbX_3$ nanocrystals provide better light yield, but the material is hygroscopic and its chemical stability is generally lower. In comparison, preparation of CdSe (as well as other selenides) is rather complicated.

There are various wet chemistry strategies to achieve desired results and there are also several key parameters to consider. The syntheses of the discussed compounds may proceed at normal or slightly elevated temperature, typical for sol-gel, precipitation or photo induced methods. However, some of the syntheses proceed only at higher temperatures, such as hot injection or certain sol-gel variants. Another issue to consider is the type of solvent, i.e. whether the syntheses proceed in aqueous or organic solutions.

To exploit the advantages and limit the disadvantages, these materials can be prepared in the form of core-shell particles, thin films, composite sandwich-like structures or they can be embedded in different matrices [2].

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Monday, 10 September 2018, 15:00-15:15 O10-Mon

The ESQUIRE project: Quantum Dots for scintillation detectors

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The ultimate goal of ESQUIRE (Experiment with Scintillating QUantum dots for Ionizing Radiation Events) is to demonstrate the feasibility of a new approach for the study of rare events such as the neutrinoless Double Beta Decay (0vDBD). This approach is based on a new category of scintillating materials containing nano-crystals coupled to high quantum efficiency optical photon sensors (SDDs). The main objective is to realize a particle detector able to reach good energy resolutions in the region of interest for the study of 0vDBD (2 % at 3 MeV). Its main feature consists in the use of a mass-scalable technology that potentially makes ESQUIRE a competitive project for next-generation 0vDBD experiments. We will report on the first results of the optical characterization measurements of the samples containing nanocrystals and the first scintillation measurements will be presented and discussed.

InGaN/GaN MQW scintillator - design and applications

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Beside traditional bulk scintillating materials new approaches based on semiconductor layers such as ZnO or GaN emerged [1], recently. We will present scintillator structure and principles of its design based on InGaN/GaN multiple quantum well (MQW) heterostructure, which offers further increase of efficiency. Nitride semiconductor heterostructures are widely used for light emitting and laser diodes as well as for high power and high frequency applications. Recently, it was shown that these heterostructures, if properly designed, can work as very efficient fast scintillators with long lifespan due to their radiation resistance [2,3]. Some principles of structure design can be adopted from light emitting diode technology, however, scintillators have in many aspects different requirements and opens new problems which were not solved, yet. First, due to the penetration depth of ionizing radiation, the active region has to be much thicker with high number of QWs. We will discuss the consequences of thick active region, e.g. formation of huge V-pits, their influence on photoluminescence (PL) properties and possibilities to suppress their size. Dependence of scintilator properties on QW number ranging from 10 to 70 will be shown. While for LED structures high level of excitation brings a problem with non-radiative Auger recombination, in the case of scintillator an opposite problem, extremely low intensity of excitation, has to be solved. Under such conditions the excitonic QW luminescence (3.2 eV) can have even lower intensity than different kind of defect bands originating either in GaN (yellow band 2.2 eV) or in InGaN QWs (2.6 eV). Since defect bands have slower decay times, they are detrimental for fast scintillator applications. The origin of these bands and different ways how to suppress their intensity will be discussed. Surprisingly, some of defect bands are very sensitive to polarization field in InGaN/GaN heterostructure, which can be influenced by doping or by structure design. Scintillator structure design will be based on results obtained from PL spectra and excitation-emission maps, AFM, HRTEM, CL, SIMS and band structure simulations by NextNano software.

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Nanocomposite polymer scintillator materials

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Polymer and crystal detectors are widely used to detect ionizing radiation. Each of these types of detectors has its advantages and disadvantages regarding scintillation parameters. However, taking into account the increasing needs for the use of detectors for radiation monitoring, significant amounts of scintillation output and their production cost are becoming key determinants. The best solution to this problem is the development of scintillation materials which would combine the low cost of plastic detectors and the high stopping power of inorganic scintillators.

The composite materials based on polystyrene, polyvinyl toluene or other polymeric matrices loaded with inorganic nanoparticles are the promising materials that could be able to combine the advantages of organic and inorganic scintillators. The study of the scintillation mechanism in such the composite materials is at the stage of the accumulation of initial experimental results and the development of the models

By developing the nanocomposite polymer scintillators, one can predict the following mechanisms of energy transfer: the transfer of the excitation energy from nanoparticles to polymer matrix, transfer of polymer matrix energy to nanoparticles, or simply the using of polymer matrix to protect nanoparticles from the influence of the moisture of air. For the case of the energy transfer from nanoparticles to the polystyrene matrix, several approaches can be considered: i) the absorption of radiation of nanoparticles by the polymer matrix; (ii) non-radiation resonance energy transfer from nanoparticles to polystyrene or to polystyrene activators; iii) excitation of a polymer matrix by electrons escaping from nanoparticles due to external photoelectric effect. All of these three approaches can exist simultaneously, but in the case of small-size nanoparticles, the electron escape outside the nanoparticle is the determining mechanism for excitation of the polystyrene matrix.

It has been demonstrated that the intrinsic luminescence of CaF_2, SrF_2, BaF_2 fluoride crystals upon X-ray excitation decreases significantly with decreasing nanoparticle sizes. The observed X-ray excited luminescence intensity falling is explained by an escape of electrons from nanoparticles in the case when the electron thermalization length or the length of free electron pass becomes larger than the size of the nanoparticle. However, when these nanoparticles are embeded into polystyrene scintillator, its luminescence increases by more than an order of magnitude, confirming the electron escape mechanism of nanocomposite luminescence excitation. So, in polystyrene composites with BaF_2 (40 weight %) the intensity of X-ray excited luminescence increased in 15, with SrF_2 - in 12, with $LaPO_4$-Pr - in 8 times.

Novel scintillating nanocomposites for X-ray induced photodynamic therapy

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Applications of scintillating materials in medicine involve, in particular, imaging systems for medical diagnostics and medical therapy. X-ray induced photodynamic therapy (PDTX) uses tumor-destroying agents based on scintillating nanoparticles conjugated with photosensitizer molecules. The agent accumulates preferentially in the target cells. Subsequent external X-ray irradiation excites the scintillating nanoparticles, emitting secondary radiation, which activates the photosensitizer molecules [1]. Their deexcitation via non-radiative energy transfer leads to the production of the reactive oxygen species, such as singlet oxygen.

We prepare highly prospective core-shell nanocomposites for PDTX based on either $Lu_3Al_5O_{12}:Pr^{3+}$ or ZnO:Ga scintillating cores. The cores are synthesized by the UV photochemical method [2], coated by amorphous silica and biofuncionalized by attachment of the protoporphyrin IX (PpIX) molecules. Resulting three layer nanocomposites feature uniform shells covering intensely luminescent cores. We study luminescence and scintillation properties of prepared nanocomposites. Room temperature radioluminescence spectra as well as photoluminescence steady-state and time resolved spectra of the materials confirm the non-radiative energy transfer from the cores to the PpIX outer layer. The singlet oxygen generation in both systems is demonstrated by the 3'-(p-aminophenyl) fluorescein (APF) chemical probe. Parasitic reaction with OH radicals is ruled out by NaN_3 used as an $^1O_2$ inhibitor. Observed features of both studied nanocomposites indicate their considerable potential for PDTX application.

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Decay time and residual stress in scintillators: a continuum mechanics approach.

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We model scintillation as a three scale phenomena: at the microscopic scale the incoming energy creates a population of excitation carriers which at the mesoscopic scale they recombine in a dissipative and non linear manner to yield photons in the visible range [1]; the link between these two scales is obtained by renormalization techniques. We assume that crystal at the mesoscopic scale a structured continuum to arrive at a Reaction-Diffusion-Drift equation which describes the excitation carriers generation and recombination process [2], coupled with the equation of electrostatics. This PDE's system generalizes the phenomenological model of [3] and closely reminds the one obtained by starting from a totally different approach into [4] for semiconductors. At the last scale, the macroscopic, scintillation is affected by the absolute temperature and the mechanical stress which appears in the constitutive parameters of the PDE's system which now contains the heat and mechanical balance equations. By following [5] and [6] we obtain results about the solution global existence and asympttic behavior in time. An explicit representation of the scintillator *Decay time* in terms of the equation physical parameters is obtained here for the first time.

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Dosimetric evaluation empoying and comparation TL response of LiF:Mg,Ti and μLiF:Mg,Ti in the clinical electron beams dosimetyr applied to total skin irradiation (TSEB) treatments

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The Total Skin Electron Beam (TSEB) irradiation is a radiotherapeutic technique that aims to provide the patient's skin surface with a more homogeneous dose, in order to treat cutaneous T-cell lymphomas, both for curative and palliative purposes. Electron irradiation penetrates a few millimeters into the skin, reaching the affected parts completely, without penetrating the internal organs. If the tumor is detected early, treatment results in the complete disappearance of all signs and symptoms of the disease [1]. In vivo dosimetry has become an important role for the treatment of total skin irradiation within a rigorous quality assurance program that should be an integral part of the radiotherapy departments. The use of TLDs in vivo can identify variations in the prescribed dose because its measurement accuracy and great precision [2]. The LiF:Mg,Ti is the most used TL material and widely studied in radiotherapy dosimetry due to near tissue-equivalence of the material, along with its overall reliability.The dosimeters of μLiF:Mg,Ti have been gaining considerable importance in the radiotherapy departments. These detectors allow measurements in vivo with great advantages due to their minimum dimensions of 1x1x1 mm^2. Thus, aiming to apply the LiF:Mg,Ti, the most common TLD material, and μLiF:Mg,Ti as easy-to-take alternatives to electron beams dosimetry and its parameters applied to TSEB, this paper reports a comparative study of the TL responses of both materials to dose evaluation in TSEB treatments. The TL response of both materials was evaluated in several TSEB parameter tests and in clinical application, evaluating the dose distribution in a treatment simulation using AldersonRando anthropomorphic phantom. The results showed that the μLiF:Mg,Ti presented greater variation of the response in relation to LiF dosemeters in some paramenters analyzed, due to the small dimensions and to evaluate doses absorbed in the surface over a large area in the treatment plan.

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EPR and Thermoluminescence for dosimetry studies of synthetical $CaSiO_3$ doped with Cr

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The most important application of Thermoluminescence (TL) is radiation dosimetry. Chromium (Cr) doped synthetic $CaSiO_3$ polycrystals have been produced by the devitrification method in the laboratory [1]. The polycrystals was characterized by X-ray diffraction, the diffraction pattern of the polycrystals doped with Cr is very similar to standard $CaSiO_3$. They are sensitive as γ-ray detectors. Grains of 75 - 180 μm were used for TL and Electron Paramagnetic Resonance (EPR) exhibit TL peaks at 120 and 247 ^{o}C, when the grains are heated between 50 and 400 ^{o}C at a rate of 4 ^{o}C/s for measurements. Both TL peaks are linear with dose from 0.2 up to 1000 Gy, TL peak at 247 ^{o}C considered to be ideal for dosimetric estudies. The EPR spectra showed two principal resonance signals with g values at g = 1,9790 and g = 4,2362, the resonance signal at g = 1,9790 is due to Cr^{3+}[2]. The EPR intensity of signal g = 1,9790 increase with the dose up to 1000 Gy, this result can be used in radiation dosimetry for doses between low and about 1000 Gy

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Study on dosimetry of mixed radiation field using TLD and TEPC

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The dose assessment of photon and neutron produced by high-energy accelerator or nuclear reactor is more difficult and complex than traditional photon or electron radiation. In most cases, photon doses are generally measured by using the thermoluminescence dosimeter (TLD), personnel photon badge, etc. Neutron doses often use gold foil activation analysis, dual TLD method or personnel neutron badge for evaluation. Tissue-equivalent proportional counter (TEPC) is commonly used to measure the beam quality for different linear energy transfer (LET) radiations, and also to measure the characteristic of energy deposition. The dose contribution of different LET radiations such as photon and neutron can be measured simultaneously using a TEPC in a mixed radiation field. This study used dual TLD chips, OSLD neutron badges and a TEPC to evaluate radiation doses at the positions around the patient in the treatment room of Boron Neutron Capture Therapy (BNCT) using the thermal neutron beam of Tsing Hua Open-pool Reactor (THOR). All used detectors were calibrated with the standard Californium-252(^{252}Cf) neutron source in the Institute of Nuclear Energy Research (INER). TLD (TLD-600 and TLD-700) chips were used as well as the cadmium difference method to evaluate the photon and neutron doses. In addition, the optically stimulated luminescent (OSL) neutron badges were also used. Besides, the distribution of microdosimetry parameters such as lineal energy y and the characteristics of energy deposition of different LET radiations were measured using a self-made TEPC. By means of the measured results of TLD and TEPC, the dose contributions of photons and neutrons in the BNCT treatment room were evaluated and compared. Characteristic of different methods for assessing photon and neutron doses in the THOR-BNCT mixed-radiation field were analyzed and discussed. In conclusion, Dual-TLD and OSL badge is suitable for low-energy neutron measurement of mixed radiation fields. However, due to the convenience of measuring different LET radiations, TEPC has a wide applicability on dose assessment in a mixed radiation field.

Thermoluminescence dosimetry of reactor neutrons in wide range of doses

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Lithium fluoride (LiF) is the most common base material used for production of thermoluminescent detectors. During heating up to 600°C high temperature emission of LiF:Mg,Cu,P detectors after exposure to high dose in the range from 1 kGy to 1 MGy has been observed at the IFJ. The main dosimetric peak (220°C) is disappearing with increasing dose and the new peaks start to appear at a higher temperature. The new high temperature peak was called 'peak B' and the UHTR (Ultra-High Temperature Ratio) method was developed and applied for dosimetry of high doses [1,2]. Due to this phenomenon MCP detectors are able to measure radiation doses from fractions of μGy up to about 1 MGy.

The aim of this work was to confirm usefulness of MCP TLDs in measuring wide range of doses in the radiation field with neutron component. To perform the experiment fifty dosimeters were prepared. Each one of them consisted of three highly sensitive ^{nat}LiF:Mg,Cu,P (MCP- N) and three ^{7}LiF:Mg,Cu,P (MCP-7) detectors manufactured at the IFJ PAN in Kraków, Poland. The irradiation took place in the Slovenian 250 kW TRIGA Mark II reactor operated by the Jožef Stefan Institute (JSI). Due to very good characterisation of neutron and photon fields and various irradiation channels of different sizes featuring different neutron and gamma fluxes and spectra, the reactor is very versatile and can be used for irradiation of various samples [3]. Experimental samples (TLDs) have been irradiated in two positions featuring large variations in neutron/photon flux and spectra, i.e. the reactor core and in the graphite reflector surrounding the reactor core with measured total doses ranging from 2 Gy up to 700 kGy.

The obtained results demonstrated that MCP detectors are able to measure doses both at Gy and hundreds of kGy level. By using the detectors based on natural lithium, containing 7.59 atomic percent abundance of Li-6 isotope, and Li-7 enriched detectors, it was possible to separate neutron and non-neutron components of the radiation field. The experiment also drew attention to the dose range in which the greatest uncertainties occur and where further research is necessary. The detailed analysis of the results will be presented during the Conference.

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Single crystals thermoluminescent detectors DTG-4

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Single crystal thermoluminescent detectors LiF:Mg,Ti, referred to as DTG-4 and crystal growth technology were developed at the Vinogradov Institute of Geochemistry over 30 years ago [1]. The crystals were grown by the Stockbarger method from fused high purity LiF. The crystals were activated with MgF2 and TiO2.

Monocrystalline detectors DTG - 4 are more advantageous against most popular powdered TLD- 100 [2]. The advantages over powdered detectors that have single crystal detectors increases reusability. Besides, in single crystal detectors the chemiluminescence is greatly reduced. Reducing own background of detector decreases the threshold dose recorded. So, it is very important to measure background radiation doses.

The detectors made from crystals grown with our technology, have linear indications in the dose range 5 × 10-5 - 1 Sv, radiation resistance up to 100 Sv, reusable over 500 times. This makes them suitable for practical use in personal dosimetry. The fading is 5% for a period of year. Fading occurs only due to loss of information at storage of the irradiated detectors. Own loss of sensitivity during long-term storage of detectors is not observed.

In this paper, we compare thermoluminescent properties of detectors DTG-4 grown in 1986 and 2016 following developed technology. The experiments showed that detectors after long-term storage possess identical properties.

To measure the dose of ionizing radiation in mixed gamma-neutron fields it is advised to employ DTG-4 detectors made of Li6 and Li7 crystals based on lithium isotopes. This paper describes the detectors grown in 1989 and 1990; it also presents the results on sensitivity of detectors, the shape of glow curve and peak ratios for DTG-4 detectors consisting of both natural lithium fluoride and Li7 isotope. The experiments have shown that sensitivity remains unchanged for both detectors after 30 years of storage. The peak ratio is also maintained, i.e. the shape of the glow curve does not change, that allows using detectors DTG-4 in practical dosimetry for a long time.

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Different components of the quartz OSL signal resolved by the TM-OSL method

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In OSL dating of geological sediments, where the zeroing of the chronological signal is assumed to be achieved by sunlight bleaching during the transport of grains before the deposition, for the age estimation, it is important to use the OSL component that can be easily bleached in nature (Fast OSL component). During the SAR protocol usually applied in OSL dating based on quartz, the simple OSL decay is measured with the stimulation wavelength of 470 nm or 530 nm at temperature 125°C [1]. Extracting the fast OSL component from the OSL curve obtained in this way is not a sensible solution mainly because of the limited accuracy of the results of such a procedure and the big number of experimental data that are usually needed for the age calculation. Thus a method of OSL measurement that enables the fast OSL component to be extracted on the stage of the experiment is highly desirable. Recently it has been shown that the thermally modulated OSL (TM-OSL) method can be successfully used for this purpose [2]. This method consists in optical stimulation with constant stimulation energy and constant photon flux during linear heating. Such treatment generates changes of the optical cross-section which decide about the significant differences between the probability of electron release from various kinds of traps. This allows the signal from different traps to be effectively separated. The stimulation of quartz with the wavelength of 620 nm during the linear heating leads to the appearance of a TM-OSL peak below 200°C. As was previously proved, it originates from the same traps that are responsible for the fast OSL component [3]. In this study the measurement series were planned in order to find the correlation of individual peaks observed in TM-OSL measurements with the OSL components earlier determined for quartz. The results of alternately repeated TM-OSL and standard OSL measurements (CW- or LM-OSL) reflect such a relation directly. The thermal stability of the individual TM-OSL peaks, which will be also presented, can additionally confirm the correlation. The selective OSL component detection after the different radiation doses allows the growth curves for the individual OSL components to be established.

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Pre-dose technique revisited for modern use in dosimentry

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The Pre-dose technique applied to quartz samples makes use of TL 110 oC peak's sensitivity changes in result of cycles of absorption of radiation dose followed by heating (Bailiff, 1994). This technique was widely used in dosimetry until the end of last century, e.g. for estimation of radiation doses after Chernobyl accident (Bailiff, 1995). Its advantage is insensitivity to light exposure, which makes it possible to apply in luminescence dating of tiny and transparent ceramic samples.

The quartz grains were extracted from four medieval bricks collected from Teutonic Castle in Torun, Poland. Equivalent doses were established with help of Blue OSL SAR protocol, which was earlier used for dating (Chruscinska et al., 2014). The same samples were also measured by Pre-Dose method. The results are presented and compared enabling optimization of parameters of Pre-dose measurement protocol.

It is expected, that applying both techniques will enable to develop possibility of chronological reconstruction of ancient buildings (e.g. by dating the moment of shielding the bricks by mortar layer). From the other hand retrospective dosimetry will also benefit from improvement of Pre-dose measurement protocol.

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Implementation of eye-lens dosimetry in Poland

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It has been seven years from the ICRP Statement on tissue reactions containing the recommendations for an equivalent dose limit for the lens of the eye of 20 mSv in a year for workers, and has been 6 years since Laboratory of Individual and Environmental Dosimetry (LADIS) provided eye lens doses measurement. Reduction of the limit for occupational exposure for the lens of the eye needs adequate approaches for eye protection and eye dose monitoring.

The most accurate method for monitoring the equivalent dose to the lens of the eye is to measure the personal dose equivalent Hp(3) with a dosimeter worn as close as practicable to the eye.

To measure eye lens doses in terms this quantity a dedicated dosimeter and the appropriate method has been developed in the largest dosimetry service in Poland.

We report results of measurements of Hp(3) from eye lens dosimeters (over 3000 readouts), issued in the years 2012-2017. In measurements high-sensitivity MCP-N (LiF:Mg, Cu, P) thermoluminescence detectors were used.

The frequency distribution of eye lens dose measurements performed using special dedicated dosimeters, via their Hp(3) operational values, over 3-month periods, after subtraction of natural background in 72% cases are below 0.1mSv. In case new operational quantity Hp(3) the percentage of workers, which exceed the new limit are 2%.

Proficiency Testing and Criteria Comparison for External Personnel Dosimeters Evaluation Laboratories in Taiwan

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The National Radiation Standard Laboratory (NRSL) of the Institute of Nuclear Energy Research (INER) always performs the execution of personnel dosimetry proficiency testing for improvement of measurement quality and traceability of related laboratories in the radiation measurement field. In Taiwan, ten external personnel dosimetry performances have been conducted according to Taiwan Accreditation Foundation (TAF) criteria — testing field of personnel dosimetry criteria and testing, and the basic concept is the U.S. test criteria— ANSI/HPS N13.11 standard. From 2016 to 2017, the tenth proficiency testing was smoothly completed under full cooperation among NRSL and the 8 tested laboratories using 5 different types of detectors. These personnel external dosimetry laboratories evaluated the doses of radiation-related matters for radiation safety in our country. The used dosimeters were of the 4 thermoluminescent dosimeter (TLD) types HARSHAW, Panasonic, RADOS and Thermo, and 1 optically stimulated luminescence dosimetry (OSLD) type LANDAUER.

All the 8 tested laboratories passed all the six- category tests. The performance quotients of 4 laboratories were below 20% and the others were below 30% which showed that the technical competence of each laboratory was pretty good. With the ANSI/HPS N13.11 standard evolving from the 2001 version to the 2009 version, related criteria applicability were also performed for different testing items and stricter limitations of performance criteria. All the participants were able to pass the proficiency testing based on ANSI/HPS N13.11-2009.

Yb-doped silica optical fibers for real-time dosimetry in radiotherapy

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Over the years, many efforts have been made to develop radiation detectors to handle the complex issues of small field dosimetry and achieve the increasing accuracy, precision, and in vivo dose monitoring required by the new advanced treatment modalities. In this context, interest has surged in the development of sensors based on radioluminescent (RL) optical fibers. However, the employment of such systems for monitoring extended radiation fields with energies above the Cerenkov threshold is still challenging, since a spurious luminescence, namely, the “stem effect,” is also generated in the passive fiber portion exposed to radiation. Previous investigations demonstrated that the RL of Yb^{3+}, displaying a sharp emission line at about 975 nm, is free from any spectral superposition with the spurious luminescence. This paved the way to their use in applications where an efficient stem effect removal is required [1, 2]. In this work, the near infrared (NIR) RL and dosimetric properties of Yb-doped silica optical fibers, coupled with an optical detector prototype based on an avalanche photo-diode, were studied by irradiating the fibers with clinical beams [3].

Yb-doped fibers have been prepared by sol-gel. Irradiations were carried out with photons and electron beams generated by a Varian Trilogy accelerator. The performances of the system in standard and small field sizes have been investigated comparing the output factor, percent depth dose and off axis ratio measurements of the prototypal dosimetric system with other commercial sensors. The NIR scintillation proves to be unaffected by the stem effect, even in unfavourable large field irradiations. The system shows a satisfactory reproducibility, good sensitivity, linear dose rate response, independence of the signal of dose rate and impinging beam orientation. The results are in good agreement with reference dosimeters in terms of relative dose profiles and output factors.

The results of this study demonstrate that the drawback due to the stem effect in Yb-doped silica optical fibres can be managed in a simple but effective way by optical filtering. The robustness of the system in complex dosimetric scenarios and the accuracy achieved by Yb-doped fibres in relative dose assessments suggest an effective use of the system for real-time in vivo dosimetry.

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Feasibility of optically stimulated luminiscence dosimetry for TPS and calculation algorithms heterogeneity corrections evaluations

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The advancing of cancer treatment techniques, such as intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) has enabled the delivery of highly conformed dose distribution to the target while minimizing the dose to the critical structures. Due to its complexities, such advanced treatment techniques demand treatment planning systems (TPSs) and dose calculation algorithms commissioning. The formalisms needed to these procedures are advised by many international recommendations of quality assurance programmes in radiation oncology. Because human body is composed of heterogeneous tissues, the characteristics of therapeutic radiation beam will be different as the beam interacts with tissues of widely differing radiological properties, so the TPSs must employ corrections and dose calculation algorithms that will account the presence of media heterogeneity. Aiming an optimum therapeutic outcome, Task Group 65 (TG 65) of the American Association of Physicists in Medicine (AAPM) stated that "the general principle of 3% accuracy in dose delivery with the corresponding need for better than 2% accuracy in correcting for inhomogeneities is a reasonable, albeit challenging, goal". Thus, this paper aims to evaluate the performance of Optically Stimulated Luminescence nanoDot (Landauer Inc., Glenwood, Illinois, EUA) dosimeters and microStar ii reader for the evaluation of TPSs and heterogeneity corrections performed by the dose calculation algorithm. The experimental measurements were performed with a 10x10x10 cm^3 home-made phantom composed of dental wax, glass mesh and aluminum to simulate tissue, air/lung tissue and bone structures respectively; 6MV photon beams from a Varian True Beam (Varian Medical systems, Palo Alto, CA) linear accelerator and nanoDot dosimeters. The phantom and dosimeters arrangement was irradiated with 10x10 cm^2 static fields and different gantry angles in order to vary the beam interactions throughout the phantom. The irradiations were planned with Varian Eclipse 13.6, and the absorbed doses obtained with the OSL system compared with two dose calculations from Varian AAA algorithm - with and without heterogeneity corrections. The experimental results show that the OSL dosimetry system microStar ii and nanoDot dosimeters are accurate enough, especially after appropriate commissioning, and able to help finding errors and/or lack of heterogeneity corrections in radiotherapy planning systems, attending the TG 65 statements.

Dose correction study of salt (NaCl) dosimeter for its energy dependence

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Salt (sodium chloride, NaCl) has thermoluminescence (TL) property as it exposed to ionizing radiation and has been used as one of the TL dosimeter (TLD) material in recent years. NaCl is cheaper compared with other commercial TLDs, but has higher energy dependence due to its higher effective atomic number. NaCl has higher responses to low-energy photons, as a dosimeter, the exposed photon energy should be noted to make a correction of the measured dose for energy-dependent properties. In this study, commercially available salt in Taiwan was used as a dosimeter material for the relevant thermoluminescent dose characteristics test. The Monte Carlos (MCNP code) method was used to simulate the dose response and energy dependence characteristics of a NaCl dosimeter irradiated by photons of different energies. In order to facilitate the positioning of NaCl powder and to place it into the Rando phantom to assess the organ doses exposed by the external radiation source, a batch of rod-shaped capsule containers was designed for the placement of NaCl powder. The outer container of the capsule is made of polyethylene and the inner volume is divided into two zones, one of which is internally coated with a layer of copper (or aluminum), and the other zone is made of only polyethylene, which is used for discrimination of (photon) energy. By the ratio of the TL reading (response) values of the two-zone NaCl powders, the energy of the incident radiation is judged. In addition, the established correlation algorithm utilizes X-ray beams of different energies built at the National Radiation Standard Laboratory in The Institute of Nuclear Energy Research for dose exposure and verification. The results and techniques established in this study can be used as an effective correction method for energy dependence of the NaCl dosimeter.

Luminescence centers in cerium doped $Y_3Al_5O_{12}$ nanocrystals

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Cerium doped $Y_3Al_5O_{12}$ (YAG:Ce) single crystal is an important and well-known luminescent material. Rapidly developed nanotechnologies allowed to obtain it in the nanocrystalline form.

Beside the well-known Ce^{3+} yellow-green emission, new intensive emission covering a broad spectral range from 2.7 eV to 3.5 eV was revealed recently in the luminescence spectra of YAG:Ce nanocrystals [1]. To elucidate its origin the comprehensive analysis of time-resolved luminescence characteristics of YAG:Ce nanopowders and nanoceramics was done utilizing UV (337 nm) laser excitation as well as pulsed synchrotron radiation in VUV spectral range of DORIS III storage ring at DESY.

Additionally, EPR experiments within the 4.6-295 K at X-band (9.4 GHz) have been carried out. The EPR spectra demonstrated the presence of several signals attributed to Ce^{3+} ions. Except the dominating resonances (about 90% of the overall signal intensity) originating from the commonly known Ce^{3+} ions at the regular Y^{3+} sites, the number of satellite ones were discovered. The latter were partly recognized as the signals coming from the Ce^{3+} placed at the Al^{3+} sites, the so-called antisite defects, earlier discussed for LuAG [2]. The rest of the minor Ce^{3+} signals have been assumed to be produced by the exchange coupled cerium ions (dimers).

Experimental data obtained in the YAG:Ce nanopowders and nanoceramics allow to infer that namely the Ce^{3+} ions substituting Al^{3+} in nanoparticle's surface are responsible for the blue-UV emission observed in the YAG:Ce nanocrystals. Blue-UV emission reaches up to 75% of the regular emission's intensity depending on the Ce^{3+} content. Both bands thus cover the 350-650 nm spectral range providing unique opportunity for white light LED fabrication.

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Structural, optical and electrical properties of ZnO nanocrystals in a-SiO_2/Si-n track templates

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In this work, we present the results on the study of ZnO nanoclusters obtained by electrochemical deposition (ECD) of zinc in track template a-SiO_2 / Si-n. The oxide layer was prepared by thermal oxidation of a silicon substrate (n type) in wet oxygen atmosphere at 900 C. The thickness of the oxide layer was 700 nm according to ellipsometry. The samples were irradiated at DC -60 cyclotron with 200 MeV Xe ions to fluence 108 ions/cm2. Irradiated samples were etched in aqueous solution of HF with Pd 0.025 g at 18 C. ECD of Zn in the template was carried out in the potentiostatic regime at a voltage range $(1.5-1.85)$ V, and pH equal 3. The surface of the precipitated samples was examined using a scanning electron microscope JSM 7500F. X$-$ray diffraction analysis of the samples was carried out on a D8 ADVANCE ECO X$-$ray diffractometer. To identify the phases and study the crystal structure, the software BrukerAXSDIFFRAC.EVAv.4.2 and the international ICDD PDF$-$2 database were used. In the electrochemical deposition of zinc in the track template, nanocrystals of zinc oxide were obtained in three crystalline phases: wurtzite, sphalerite, and rock salt structure. It should be noted that the type of structure depends on the voltage applied to the electrodes. The optimum ECD regime was established, with obtaining the most widespread phase of ZnO, wurtzite. Luminescence, voltage-current characteristics were investigated for three crystalline phases of ZnO nanocrystals.

Sub-nanosecond excitonic luminescence in ZnO:In nanocrystals

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ZnO possesses fast excitonic luminescence at 300K with decay times in sub-nanosecon time region. This gives grounds for use ZnO as a fast scintillators. Along with excitonic luminescence the luminescence of defect states in 450-650 nm spectral region with decay times in microsecond region usually is present Previously, it was found that doping with Ga or In suppress the defect luminescence in ZnO optical ceramics [1]. In the present study ZnO:In nanocrystals (NC) were obtained in a Heliotron reactor (PROMES CNRS, France) via the solar physical vapor deposition (SPVD) method [2]. The TEM, SEM, XRD and EDAX were used for ZnO:In NC characterization (indium concentrations were 0.5; 1.0; 2.0 and 3.0 wt%). Photoluminescence decay kinetics were studed under 1 ns 266 nm YAG:Nd laser excitation and under wavelength-tunable picosecond (30 ps) solid state laser (max excitation energy density is less than 200uJ/cm2), the luminescence spectra and decay kinetics were measured with Streak-scope C4334 (HAMAMATSU).

Just like in optical ceramics [1] in ZnO:In NC defect luminescence band is suppressed. The decay time of exciton luminescence is less than 1ns and and reaches 19 ps depending on indium concentration.

At 9K the ExD0 (3.35 eV) and more intensive peak at 3.217 eV were detected and the origin of this peak is still under investifgation. It is assumed that the band is associated with excitons bound at shallow donor centers formed due to indium doping.

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Luminescence characteristics of InGaN/GaN heterostructures and their temperature dependences

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Gallium nitride (GaN) is a binary direct bandgap semiconductor commonly used in optoelectronic, high-power and high-frequency devices such as light-emitting diodes (LEDs) and high electron mobility transistors (HEMTs). High-brightness GaN LEDs completed the range of primary colors, and made applications such as daylight visible full-color LED displays, white LEDs and blue laser devices possible. These LEDs are based on InGaN/GaN heterostructures grown by Metal-Organic Vapour Phase Epitaxy (MOVPE) on standard c-plane sapphire substrates. In recent works, InGaN/GaN heterostructures are investigated also as highly promising scintillating materials [1-2]. Their advantages are high radiation resistance, high exciton binding energy, and consequently short excitonic decay time below 2 ns as well as high luminescence efficiency at room temperature. A demand for very fast, efficient scintillators with a decay time of few nanoseconds was created in the recent years due to the decreased size of integrated circuit structures down to a nanoscale and the necessity of fast scanning electron microscopes for inspection machines in the electronics industry. High energy calorimetry, as well as the time of flight imaging such as positron emission tomography, would also greatly benefit the drastic improvement of the scintillating timing performances, for these applications of nitride heterostructures are highly promising, see for example [3] and references therein. In this work, InGaN/GaN multiple quantum well (QW) structures with different numbers of QWs will be prepared by MOVPE technology and will be studied by means of time-resolved photoluminescence spectroscopy whereas special attention will be given to photoluminescence excitation, photoluminescence emission spectra as well as photoluminescence decay times and their temperature dependences. Obtained data will be further analysed and discussed as for their potential use in scintillating applications, where large QW number covering particle penetration depth is necessary, and fast luminescence response is required.

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X-ray exited luminescence decay kinetics of SrF_2 and CaF_2 nanoparticles in exciton diffusion model

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Nanomaterials often show differences in luminescence and scintillation properties comparing with bulk materials caused by the influence of various size effects. In particular, the decay kinetics of self-trapped excitons (STE) luminescence under X-ray excitation reveals a fast component that is practically absent in their single crystal analogues. The contribution of the fast component increases with decreasing nanoparticle size. This component is attributed to the quenching of the STE luminescence due to the interaction of excitons with near-surface defects.

The dependence of the STE luminescence kinetics on nanoparticle size under X-ray excitation for SrF_2 and CaF_2 nanoparticles has been studied. These nanoparticles are interesting both from the point of view of fundamental study of luminescent processes in wide-band dielectric materials and the practical applications as nanoscintillators.

SrF_2 and CaF_2 nanoparticles were synthesized by the chemical co-precipitation method. Such the synthesis provides the possibility for obtaining of nanoparticles with 20 nm and 25 nm of size for SrF_2 and CaF_2, respectively. In order to obtain nanoparticles with different sizes, the nanoparticles were annealed at temperatures 200, 400, 600 and 800^{o}C.

To describe the decay luminescence kinetics and to explain the appearance of a short decay component, a model is used in which the quenching of exciton luminescence occurs due to diffusion of excitons to the surface of nanoparticles [1]. It is assumed that quenching occurs in an infinitely thin near-surface layer with an infinitely high quenching rate of excitations. Within this model, agreement was obtained with the experimental results for an average value of the exciton diffusion length about 15 nm for SrF_2 and 19 nm for CaF_2.

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Thermally and optically stimulated luminescence in long persistent SrAl2O4 co-doped with Eu2+, Dy3+ and Eu2+, Nd3+

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The long persistent luminescence, thermoluminescence and IR stimulated luminescence properties of two monoclinic strontium aluminates $SrAl_2O_4$ co-doped with Eu^{2+} ,Dy^{3+} and Eu^{2+} ,Nd^{3+} exposed to beta radiation is reported. The phosphors were synthesized by the combustion method followed by a post-annealing treatment under a reductive carbon atmosphere. Photoluminescence consist of the main peak at 515 nm, which is typical for Eu^{2+} emission in $SrAl_2O_4$ phosphors and two weak bands at 405 and 425 nm of unknown origin. After exposure to beta radiation the Dy and Nd co-doped phosphors exhibit intense intense TL peaks at 60 and 80 °C and weaker TL peaks at 140 and 160 °C, respectively. Additionally, both phosphors exhibit a weak TL between 250 and 400 °C. The thermal empting of the traps related to the low temperature TL peaks creates ultra-long intense AG, which gradually decays with time and remains detectable after 220 h storage in dark. IR stimulation of beta irradiated phosphors creates intense IRSL, which is related to the release of electrons from the traps responsible for the low temperature TL peaks.

Luminescence and scintillation properties of Mg2+ -codoped (LuxGd3-x)Al2Ga3O12:Ce (x = 0.2 - 0.8) single crystals

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The luminescence and scintillation properties of Mg^{2+}-codoped $(Lu_xGd_{3-x})Al_2Ga_3O_{12}$:Ce (LGAGG:Ce,Mg) (x = 0.2 - 0.8) single crystals are presented. The crystals were grown by micro-pulling down method [1]. The Ce^{3+} $5d_1$- 4f luminescence band was blue-shifted with increasing Lu content due to a decrease in crystal field splitting of the 5d levels. The light yield (LY) and scintillation decays were measured under excitation with 662 keV g rays. The LGAGG:Ce,Mg crystals exhibit faster scintillation decay time with slight decrease of LY value compared to non-codoped LGAGG:Ce ones. The scintillation decay was accelerated with increasing Lu content. The LGAGG:Ce,Mg (x = 0.2) crystal exhibits high LY of 40,500 photons/MeV and dominant decay time of 62 ns (73%), whereas those values of 38,500 photons/MeV and 52 ns (73%) are obtained for the LGAGG:Ce,Mg (x = 0.8) one. The dependence of LY on an amplifier shaping time was also measured to investigate the contribution of slow component in the scintillation pulse [3].

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Optical and scintillation characteristics of Li+ -codoped Gd3Al2Ga3O12:Ce single crystal

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Optical and scintillation characteristics of Li^+ - codoped $Gd_3Al_2Ga_3O_{12}$:Ce (GAGG:Ce,Li) crystal [1], grown by Czochralski (CZ) method, are presented. Photo- and radio-luminescence spectrs, light yield (LY), energy resolution, scintillation decay time and coincidence timing resolution were measured. The GAGG:Ce,Li crystal shows high LY of 49,000 photons/MeV and principal decay constant of 80 ns. At 662 keV γ rays, energy resolution of GAGG:Ce,Li coupled to R6231photomultiplier tube was measured to be 6.5%. The GAGG:Ce,Li crystal exhibits a faster scintillation decay time with an expense of LY value compared to a non-codoped GAGG:Ce one, which results in a superior coincidence timing resolution [2]. Temperature dependence of radioluminescence intensity and photolumunescence decay time were investigated and activation energy for thermal quenching was determined based on temperature-dependent decay times [3]. The afterglow and thermally stimulated luminescence (TSL) characteristics were also investigated.

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2D reader for dose mapping in radiotherapy using radiophotoluminescent (RPL) films

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Among luminescence techniques, Al_2O_3:C,Mg based Radiophotoluminescence is a suitable candidate for medical dosimetry, when compared with commonly used detectors (OSL: Al_2O_3:C, BeO and TL: LiF:Mg,Cu,P, LiF:Mg,Ti), because of its nondestructive readout procedure and lack of light sensitivity. These are clear advantages, since there is no need of light packing or handle the material in dark environment, and the dose assessment is done cumulative, which permits re-readings.Healthy tissue complications due to differences between the planned and delivered dose distributions creates a need for precise 2D and 3D dosimetry verification of the delivered dose.Radiographic films have been used for 2D dose assessment for decades and since recent years new types of films and film-like dosimetry detectors have appeared, such as radiochromic films and TL/OSL detectors. Radiographic and radiochromic systems have inherent limitations, such as narrow dynamic range, energy dependence, processor dependence, variation in optical density or limited resolution. Much focus is dedicated to the response of such films and on the development of new materials, but few works describe readout systems.In this work we describe a system developed in the Belgian Nuclear Research Centre capable of scanning RPL 2D films based on Al_2O_3:C,Mg micro crystals (47 um). The performance of the system is described in terms of several tests, where films were irradiated with a calibrated Co^{60} source. The results presented in this work are: reproducibility of the readings, Minimum Detectable Dose (MDD), dose response and spatial resolution of the system. Additionally, different profiles (3x3, 5x5, 7x7 and 9x9 cm^2) from RPL films irradiated with 6MV X-ray (LINAC) were compared with two other dosimetric systems: CC13 and radiochromic films (Gafchromic EBT3).The system is based on an X-Y moving table (Zaber - Motorized Stage) and a readout head comprising a red diode laser (635 nm) module, Multi Pixel Photon Counter (MPPC, Hamamatsu), optical filters and focusing lenses. The readout is controled by a LabView based software, where the user can select the area to be scanned, the pixel separation (step size of the scanning, by default 0.2 mm) and the pixel dwell time (period of the pixel scanning, by default 10 ms).The preliminary results show that the RPL readings are reproducible, with variation below 3 %, within the 6 readings, for test films irradiated with doses of 1 and 60 Gy. The system has a spatial resolution of 0.86 ± 0.06. The RPL films exhibits a linear (1-3 Gy), supralinear (3-70 Gy), and saturation behavior (> 70 Gy). The MDD is around 500 mGy, and this value can reach 100 mGy, by reducing the speed of the readout. The measured profiles agree with EBT3 films and CC13 by 5%. The 2-D scanning system is able to measure RPL signals accurately, and can be further used for different materials.

Luminescence Efficiency of Al2O3:C,Mg Radiophotoluminescence in charged particle beams

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The application of heavy charged particle (HCP) in radiation therapy offers significant advantages in comparison with conventional photon therapy. The physical properties of HCP enable a high local dose deposition in a well-defined depth (Bragg peak), while sparing healthy tissues surrounding the tumor.The response of solid-state detectors as a function of LET has been reported for most of the detectors that are commonly used in medical dosimetry (e.g. Al_2O_3:C, LiF) and because of ionization quenching it is known that the so called luminescence efficiency of these detectors decrease with LET. In the present work, we analyze the response from Al_2O_3:C,Mg 2D radiophotoluminescence (RPL) films and single crystals (Landauer *Inc.*) related to its luminescence efficiency when exposed to different LET. Al_2O_3:C,Mg is known as fluorescent nuclear track detector (FNTD) and has demonstrated high efficiency detection of HCP of different type and LET. Although FNTDs allow to microscopically visualize single tracks, it does not allow to macroscopically depict beam profiles or single Bragg peaks which could be enabled by using RPL films. In this work, films and single crystals (FNTD) were exposed to different ions: 70, 160, 230 MeV of ^{1}H; 100, 150 MeV/u ^{4}He; 490 MeV/u ^{28}Si ; 500 MeV/u ^{56}Fe and 290, 400 MeV/u ^{12}C at the Heavy Ion Medical Accelerator in Chiba (NIRS, HIMAC, Japan) and the RPL response was measured in SCK-CEN facilities using an in house developed 2D reading system. The RPL response to HCPs was described by the luminescence efficiency of RPL intensity, for HCPs, relative to the standard low LET radiation, gamma radiation (^{60}Co). The preliminary results show a lower efficiency of Al_2O_3:C,Mg samples in HCP compared to gamma radiation, for example, samples exposed to ^{1}H (230 MeV, LET: 0,385 keV/μm) presented 20% of decrease in the efficiency.For the ^{12}C (290 MeV/u, LET: 11,72 keV/μm) and ^{56}Fe (500 MeV/u, LET:168.3 keV/μm) irradiations, the efficiencies decreased in 65 % and 75 % respectively. The dose response of samples irradiated with ^{12}C (290 MeV/u; LET:11.72 keV/μm) presented linear behavior from 2 to 10 Gy and from 1 to 30 Gy for samples irradiated with ^{1}H (70 MeV; LET: 0.896 keV/μm). The present work aim understand how the Al_2O_3:C,Mg will respond to different HCPs and energies and to provide new possibilities for 2D dose assessment using RPL luminescent techniques.

Radioluminescence of yttria-aluminoborate glasses with huntite-like composition

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Yttria-aluminoborate (YAB) glasses have been proved to be a suitable matrix for rare earth ions. Within the compositions available in the glass-forming region of the Y_2O_3-Al_2O_3-B_2O_3 system, an interesting solution for optical materials can be found for composition with molar ratios close to that of $YAl_3(BO_3)_4$. In YAB crystals this composition leads to a stable polymorph, isostructural to natural huntite ($Mg_3Ca(CO_3)_4$) crystal, which has been extensively investigated for the realization of active optical material. In the case of YAB glasses, it has been proved that it is possible to obtain amorphous materials where the randomly distributed units share common features with the huntite-like structure. These glasses have the unusual property of ensuring a minimal distance between Ln ions. As a result, the concentration quenching effects drastically diminishes even at concentration of $30x10^{20}$ Ln at/cm^3 [2] making these glasses the ideal hosts for rare earth doped optical materials [3]. Here I will present the characterization of radio- and photoluminescence properties of YAB glasses with general huntite-like composition - $10Y_2O_3$:$30Al_2O_3$:$60B_2O_3$ - and with Y ions substituted by Ce, Tb and Dy ions. Glasses were prepared by melt-quenching method. The optical characterization shows strong photo- and radio- luminescence response for all investigated samples. Time resolved photoluminescence analysis demonstrates that Ce emission is not compromised even at doping levels as high as 9 % mol. More interestingly, for low doping level, optical activity of Ce ions is compatible with a Ce location in positions with trigonal prismatic geometry as occurs in huntite-like single crystals. In addition, the optimized co-doped Ce/Tb sample has a radioluminescence efficiency comparable to bismuth germanate ($Bi_4Ge_3O_{12}$) crystals.

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Characterization of heavy and fast Lu-containing scintillation crystals of garnet and perovskite structures

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Now, Lu-containing single crystal scintillators of garnet ($Lu_3Al_5O_{12}$ - LuAG) or perovskite ($LuAlO_3$ - LuAP) structures [1,2] doped with Ce^{3+} or Pr^{3+} are tested in various applications as (i) X-ray imaging or even micro-imaging accessories [3], (ii) Positron Emission Mamography (PEM) [4] and (iii) in similar ones. As was mentioned the most used scintillating dopants are Ce^{3+} or Pr^{3+} rare earth ions but also Sc^{3+} one was studied recently [5]. Our goal and the objectives of this paper are detailed characterization of scintillating properties of the above mentioned Lu-containing and doped scintillators. Scintillation properties include studies of N_{phels} photoelectron and L.Y. light yields, energy resolution, non-proportionality, scintillation decays and some other properties [2].

Detailed investigation of scintillation properties of these Lu-containing single crystals of garnet structure show that: (i) the highest L.Y. 27500 ph/MeV exhibit LuAG:Ce^{3+} crystals while those of Pr^{3+}- or Sc^{3+}-doped ones exhibit L.Y. up to 20500 ph/MeV or 7800 ph/MeV, respectively, (ii) heavy LuAP:Ce^{3+} crystal exhibit L.Y. 12700 ph/MeV, (iii) the best energy resolution at 662 keV 5.6 % has LuAG:Pr^{3+} crystal and this crystal exhibits also the best non-proportionality 80 % at 15 keV. In this report we will also discuss and summarize fast and slow scintillation decay components, the intrinsic and statistic energy resolutions and processes of connected with escape peaks which are clearly evident in Pr^{3+}-doped LuAG crystal, especially.

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Influence of indium-doping on the band gap of alkaline earth fluorides crystals

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The presence of traps adversely affects the scintillation processes in crystals, due to the trapping of electrons and holes at shallow energy levels. Such traps tighten the luminescence process, which worsens the time resolution of the scintillator and its light yield. Therefore, in order to improve the quality of the scintillators, the traps must either be completely eliminated during the growth of the crystal or their capture cross-section reduced by targeting another structural defect next to the trap (the so-called "defect engineering").

There is another way to get rid of shallow traps - the introduction of a co-activator with a high third ionization potential, which leads to some changes in the band structure of the crystal: band shift, narrowing of the band gap or expansion of the conduction band, depending on the matrix, activator and concentration of the activator. Such a decrease in the influence of shallow traps when introducing the co-activator Ga^{3+} is well shown for Lu3Al5O12 in [1].

In this paper we present the results of an investigation of the indium ions influence on the scintillation properties of crystals of alkali-earth fluorides. The investigations were carried out by both optical spectroscopy and non-empirical quantum chemical calculations. Our study was focused on the CaF_2, SrF_2 and BaF_2 crystals doped with In ions, but in addition, the results of studies of SrF_2 with double activation (Ce and In ions) will be presented. The calculations have been performed within GGA-PBE and GW_0 methods implemented in VASP (Vienna Ab initio Simulation Package) computer code. The calculated data along with experimental spectra allow to characterize the energy levels of the traps in the band gap.

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Influence of Mg codoping on excitation dynamics in GAGG:Ce scintillators

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Fast scintillation detectors are currently on demand for many applications in high-energy physics, medical imaging devices, and inspection tools, thus, a deeper insight into the processes responsible for the rise time of luminescence response is necessary to purposefully engineer the timing properties by scintillator composition, doping and growth conditions.

This research is focused on the study of carrier dynamics in prospective scintillators based on Ce-doped $Gd_3Al_2Ga_3O_{12}$ (GAGG). Optical pump and probe technique was employed to follow the population of different states by nonequilibrium carrieers. 200-fs-long laser pulses were used for excitation at different photon energies by using optical parametric generator to selectively excite certain structural units in the crystal. The white light continuum with tunable delay was used for probing. The difference in the optical absorption (in the range of 460-950 nm) with and without the pump (the differential absorption, DA) was measured as a function of the delay between the pump and probe pulses. The DA in this spectral region was caused by the induced absorption, which is proportional to the density of photoexcited carriers.

Samples of GAGG doped with Ce, codoped by Mg, Ti and without any intentional doping were compared. After a short-pulse resonant excitation to 5d1 level of Ce, the DA signal appears instantly and decays with the same time constant of about 50 ns in all the samples. After resonant excitation to 5d2 level of Ce, the DA signal builds up within a few tens of picoseconds in a sample without codoping, while the DA rise time was by an order of magnitude shorter in the crystals with Mg codoping even at the level as small as 10 ppm. The additional codoping with Ti, which is used to increase the light yield of GAGG:Ce,Mg does not deteriorate the DA rise time. The decrease of DA signal rise time in codoped samples was explained by the influence of Mg-codoping facilitating the electron transfer from conduction band to activator ions. The excitation directly to the trapping levels enabled revealing the DA components related to free carrier trapping and transfer to Ce ions. The numerical modeling of the DA kinetics enabled us to compile an excitation transfer diagram in GAGG crystal with and without codoping by divalent magnesium.

Validation of the model of TSL isothermal decay of dosimetric α-Al_2O_3 crystals

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Deep traps are known to determine to a large extent the luminescent properties of dosimetric α-Al_2O_3 crystals. Therefore, the study of the role of deep trapping centres in charge carrier transfer processes and thermally stimulated luminescence (TSL) is an important task. An unusual effect of isothermal build-up of TSL in the peaks at 370-450 ^oC related to deep traps was found in the samples irradiated with a high dose of a pulsed electron beam [1]. The observed TSL build-up was interpreted in terms of a kinetic model taking into account the process of thermal ionization of the excited states of F-centers. New experimental results are certainly needed for the model verification. In particular, the spectral and time characteristics of isothermal decay in other TSL peaks, e.g., at 300 ^oC need to be carefully studied using various crystal irradiation techniques.

The aim of the present work is to study isothermal decay in the TSL peaks associated with deep traps and to obtain new data verifying the TSL model, which considers thermal ionization of F-centers.

The samples of commercial TLD-500 (Al_2O_3:C) detectors were studied. TSL was excited with X-rays, UV radiation, or a pulsed electron beam (130 keV).

It was found that in the samples exposed to UV radiation the curves of isothermal TSL decay in the 300 ^oC peak are significantly different at the registration of the luminescence of F-centers (410 nm) or trivalent chromium ions (693 nm). A noticeable TSL build-up is observed only for the F-luminescence band. Moreover, it was found that the build-up amplitude of the TSL peak at 300 ^oC in the samples excited with a pulsed electron beam is much lower than that after irradiation by UV light in the region of F-centre absorption. This difference can be explained by the fact that only electron traps are filled due to ionization of F-centers in the samples exposed to UV radiation. The population of both electron and hole centres changes upon the excitation in the region of interband transitions, leading to different TSL build-up characteristics. In addition, the TSL curve at 370-450 ^oC of the studied samples was found to have a complex structure consisting of at least two overlapping peaks at 400 and 430 ^oC. It was established that the TSL build-up in the 380-450 ^oC range is associated with the presence of electron traps responsible for the TSL peak at 430 ^oC. A model describing the obtained results is developed.

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LuAG:Pr Codoped with Ho^{3+}: Acceleration of Pr^{3+} Decay Using Energy Transfer

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Lutetium-aluminum garnet (LuAG) activated with Ce^{3+}or Pr^{3+} is well-known scintillator material that attracts attention of researchers since the beginning of the century. Thanks to its favorable properties like absence of thermal quenching to 500 K or mechanical and chemical stability it has found applications in several radiation detection fields. High density (6,7 g/cm^{-3}) and effective atomic number (63) make these scintillator suitable also for detection of hard X-ray and γ radiation. On the other hand, it is not applicable for low-background experiments due to the intrinsic radioactivity generated by unstable isotope ^{176}Lu. Performance of LuAG based scintillators is degraded by anti-site defects that produce cause significant deceleration of response and lowering of light yield by trapping charge carriers during transport stage. This problem can be partially suppressed by band-gap engineering using Gd and Ga admixing and Mg^{2+} codoping [1, 2].

Modern applications, e.g. particle detection in high energy physics or medical imaging, require very fast response and 60 ns decay of Ce^{3+} or even 20 ns of Pr^{3+} in LuAG is no more sufficient for these purposes. We present an innovative method that enables further acceleration of inherent decay of activators. The method is based on creating an additional deexcitation channel by embedding a proper luminescence center into the system. Resonance between emission and absorption spectra of the centers enables a transfer of excitation energy away from activator through multipolar interaction. Energy transfer leads to higher rate of deexcitation and faster response of activator.

In this work we present effect of introducing Ho^{3+} into LuAG:Pr^{3+} single crystal grown by micro-pulling down method, particularly on acceleration of Pr^{3+} decay. Transfer of excitation energy is enabled through spectral overlap of Pr^{3+} 5d-4f emission and 4f-4f absorption lines of Ho^{3+} and provides an acceleration of Pr^{3+} decay (Fig. 1). The data were analyzed using Förster-Dexter model [3] in wide range of Ho^{3+} concentration. The extracted results can be used for precise decay time tailoring of YAG:Ce by Ho^{3+} codoping.

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Effects of Gd2O3 content on luminescence and scintillation properties of Ce3+ - doped SiO2 - Al2O3 - BaF2 - Gd2O3 glasses

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Scintillating glasses with host compositions (in mol.%) of (65-x)SiO_2 - 20Al_2O_3 -15BaF_2-xGd_2O_3 doped with CeO_2 (1 wt.%) were prepared by melt-quenching method under a CO reducing atmosphere [1]. The characteristic emission band of the Ce^{3+} 5d - 4f transition in spectral region 310 -530 nm was observed in the photo- and radio-luminescence spectra. The emission maximum shifts to longer wavelength with increasing Gd content in the glass host. The integral scintillation efficiency of about 80 % of the $Bi_4Ge_3O_{12}$ scintillator was obtained for a 15%Gd_2O_3 glass sample. Light yield (LY) and energy resolution were measured under excitation with a - and g - rays and the LY ratio (a/g ratio) was estimated. The 15%Gd_2O_3 glass shows a LY of 2050 photons/MeV with an energy resolution of 15.8% at 662 keV g rays, while the value of 240 photons/MeV (13.3%) was obtained at 5.5 MeV a particles. The dependence of LY on sample height was measured and light loss coefficient was determined [2]. The mass attenuation coefficient at 662 keV g rays was also determined and discussed [3].

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Synthesis and thermoluminescence of $KMgF_3$ perovskite doped with thulium or chromium ions

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Thulium and chromium ions doped $KMgF_3$ single crystals or powders chip were studied using thermoluminescence (TL) and optical absorption techniques.

Single crystals were grown by Bridgman method and powder samples were prepared by solid state reaction. The $KMgF_3$perovskite compound was identified using X-ray diffraction (DRX). The morphology and segregation of dopants was investigated by scanning electron microscopy (SEM). The Raman analysis showed that Cr_2O_3 phase was formed in chromium-doped samples. The XPS spectra suggest that chromium ion is bonded to oxygen and fluoride ions. The optical absorption property of the samples was analyzed between 240-850 nm. Impurities often give characteristic bands in absorption spectra. In thulium or chromium doped samples the absorption increases as the impurities concentration increased. Electrons can be trapped under irradiation process and eventually induced color centers bands (F, F_2, F_3). The polished crystalline samples were irradiated to determine changes in the absorption bands that were related with color centers and their aggregates after ageing time. Bands centered at 277, 398, 437 and 557nm were radiation-induced.

Also, the TL response as a function of the given dose was obtained using beta and gamma radiation for both kind of samples, chips and crystals. The samples were exposed to $^{90}Sr/^{90}Y$ beta source between 5 mGy and 1 Gy, and a linear dose-response was observed. The samples were also irradiated with high gamma doses between 0.1 to 10 kGy using a ^{60}Co irradiator. The samples doped with thulium showed three TL peaks with maxima at 100°C, 150°C and 220°C, the increment of the TL intensity was proportional to impurity concentration. On the other hand, samples doped with chromium show two peaks at 99°C and 154°C, in this last case the TL intensity was decreasing at higher concentrations of the impurity that was ascribed to the aggregate stage of the chromium in this phosphor.

Comparative study of optical, luminescence and thermoluminescence properties of beryllium oxide ceramics and single crystals

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Contemporary solid-state dosimetry widely uses a variety of dielectric materials as radiation detectors. In many cases, such detectors use the phenomena of optically stimulated luminescence (OSL) and thermoluminescence (TL). To optimize their characteristics, a variety of optical materials are used in solving various practical problems, and many research works are devoted to the study of the OSL and TL properties of optical materials. BeO has a great potential to be considered as a working substance for TL and OSL-detectors. The main advances of BeO are a combination of high detector sensitivity to radiation effects and at the same time high radiation hardness and tissue-equivalence. Because of these properties, BeO has been intensively discussed for many years, e.g. [1]. The most suitable forms of working substance are powders, thin films, ceramics, and the like. However, an in-depth study of basic physical processes requires the study of model processes on single-crystal samples.

This research work reports the results of a comparative study of the optical, luminescence and thermoluminescence properties of beryllium oxide ceramics and single crystals. The BeO samples in the form of hot-pressed ceramics and single crystals, synthesized at the Ural Federal University, were investigated. Ceramic samples of BeO, optimized for OSL-applications, corresponded to previously reported [2]. Both undoped and Mg, Zn-doped BeO single crystals were grown from the sodium-tungstate flux, using technology [3]. Their luminescence propertieshave been reported in [4, 5]. Our investigation consists of the studies of X-Rays induced luminescence (XRL), photoluminescence (PL), TL, and OSL. The TL and OSL dependences on the absorbed dose were studied. The luminescence studies have shown the differences in PL-spectra at low temperatures for doped crystals in comparison with ceramic and pristine beryllium oxide. The changes in TL and OSL also were reviewed. In particular, the TL and OSL intensities of ceramics is at least one order higher than that for single crystals. In addition, the TL-peak of ceramics is shifted to low-temperature area in comparison with that for the single crystals. All the samples have a linear dependence of TL or OSL intensity on absorbed dose, but ceramics is more sensitive for low-doses than the single crystals.

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Luminescence study of ScF_3 single crystals under UV-VUV, X-ray and electron beam excitation

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ScF_3 maintains a simple cubic ReO_3 type structure down to at least 10 K and exhibits a rare property of isotropic negative thermal expansion over a large temperature range.

In order to reveal the manifestations of the negative thermal expansion effect in optical spectra, we have performed the following investigations.

(a) Detailed comparative study of the excitation and emission spectra for both macro-powder and single crystaline ScF_3 samples in the spectral range 2 6 eV and a wide temperature range 10 300K.

(b) X-ray and cathodoluminescence analysis of ScF_3 single crystals

(c) Thermally stimulated luminescence (TSL) study between 80 and 350 K, excited by an electron-beam (10 keV), X-rays or VUV radiation.

From the analysis of the experimental results, we obtained the information about intrinsic and extrinsic luminescence channels of the relaxation of the electronic excitation. From the TSL data analysis and the comparison with other metal fluorites, we can conclude that in ScF_3 there is the effective self-trapping of holes in the form of V_k centres and their thermal destruction occurs at about 100 K. From the creation (excitation) spectra of several TSL peaks as well as the VUV-luminescence excitation spectra obtained using synchrotron radiation at MAX-Laboratory in Lund, we can conclude that the value of band gap energy in ScF_3 exceeds 11 eV. Obtained results are compared with recent *ab-initio* calculations of electronic structure of ScF_3.

Finally, we discuss the influence of oxygen-related defects and Gd3+ ions on luminescence properties of ScF3.

Study on the growth and formation mechanism of the slow luminescence component in pure CsI scintillation crystals

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Pure or undoped CsI crystal is one of scintillation crystals with fast decay time and has been selected as detection materials for Mu2e project[1]. However, the slow component existing in the crystal is not acceptable for real application. But its formation mechanism is unclear so far. In order to reveal the relationship between slow components and growth condition, several undoped CsI crystals were grown and annealed under different condition in our lab. Undoped CsI crystals can be grown with Bridgman methods within vauum and non-vacuum atmosphere. In non-vacuum method, CsI powder with purity of 5N doped with oxygen scanvenger is charged into platinum crucible. And in vacuum, CsI powder is charged into fused silica crucible coated with carbon film, which was then evacuated under 10^{-3} MPa before sealing. The crystals were grown in the furnace with two temperature zones and temperature gradient of 25-30°C/cm. A bulk CsI crystal with size of F50×200mm was obtained, which is transparent, colorless and without any visible inclusions.The crystals grown within vacuum are more transparency than those grown in non-vacuum. Its optical transmission decreases to zero at 240nm, which is 10nm shorter than that reported in literature[2]. The emission spectra excited by UV, X-ray and g-ray from ^{137}Cs have maxim at 312nm, 315nm and 308nm respectively. Apart from this emission peak, a weak emission band, slow component peaking at 420nm was also observed. The decay times under excitation with pulse X-ray and cosmic rays were fitted into two components, 2-3 ns and 18-22 ns respectively, which are in good agreement with those reported by[3]. Several annealing experiments were carried out within different atmosphere, such as vacuum, N_2, air and iodine vapor. Their X-ray excited luminescence spectra were measured and used to evaluate the the slow/fast ratio. It was found that the slow components peaking at 420nm depends on the growth technology, annealing condition, and atmosphere. Based on these experiments, the formation mechanism of slow components were proposed and discussed in this paper.

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Luminescence and scintillation properties of (Gd3-xLux)Al2Ga3O12:Ce (x = 0, 1, 2) single crystals

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The luminescence and scintillation properties of Czochralski-grown $(Gd_{3-x}Lu_x)Al_2Ga_3O_{12}$: Ce1% (x = 0, 1, 2) single crystals [1] are presented.With increasing Lu content in this garnet host, the $5d_2$absorption band was red-shifted while the $5d_1$absorption and $5d_1$- 4f emission bands were blue-shifted due to a decrease in crystal field splitting of the 5d levels. The light yield (LY), energy resolution and scintillation decay were measured. An acceleration of scintillation decay with an expense of LY value was observed with increasing Lu content. The coincidence time resolution was measured in coincidence experiment with a fast BaF_2detector [2]. The total mass attenuation coefficients at 60 and 662 keV γ- rays were also determined and discussed [3].

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Thermally stimulated luminescence in irradiated submicron hexagonal prisms of crystalline aluminum nitride

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Spectral and kinetic regularities of thermally stimulated luminescence (TSL) in aluminum nitride crystals with 0.1-2.0 μm particle size were studied. Samples of AlN were grown using original installation by gas-phase synthesis with simultaneous treatment of liquid Al by gaseous AlF_3 and NH_3. Synthesized single crystals in form of submicron hexagonal prisms had Al deficit with Al : N = 0.9 : 1 ratio, main impurities were oxygen (1.6 at. %) and silicon (0.5 at. %).

Spectra of TSL were measured for 250 - 650 nm wavelength range at 0.4 K/s heating rate in continuous scanning mode using Perkin Elmer LS55 spectrometer with developed high temperature attachment. Preliminarily annealed samples were irradiated by KLAVI-R pulse electron beam gun (energy - 150 keV, pulse length - 2 ns, pulse frequency - 1 Hz, total amount of pulses -128).

Spectral and temperature dependencies had single peak with E_{max} = 2.92 eV emission maximum at T_{max} = 340 K with w_E = 0.74 eV and w_T = 71 K halfwidth according to peak shape estimation. Numeric analysis of experimental TSL curves in frame of general order kinetics formalism was performed. It was shown that ones can be satisfactorily (R^2=0.998) approximated by single component with E_a = 0.55±0.02 eV activation energy, s = (1.2±0.3)*10^7 s^{-1} frequency factor and b = 3.0±0.1 kinetics order parameter. It was assumed that there were competitive processes in microscopic mechanism of TSL under observation.

Obtained data were analyzed in comparison with spectral and kinetic TSL parameters of previously studied bulk AlN single crystals and independent results. Registered emission was attributed to oxygen-related centers. Thermally stimulated processes in synthesized submicron AlN crystals and impurities composition effects on its luminescent properties were discussed.

Light yield non-proportionality, intrinsic resolution and α/γ ratio of oxide crystal scintillators

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In this work, we investigated the α - particle response of well-known and new oxide single crystal scintillators and related to the non-proportionality of light yield under excitation with γ rays. The light yield and energy resolution measurements were performed at 32, 60 and 662 keV γ rays and 5.5 MeV α particles.The α-particle response in $Lu_3Al_5O_{12}$:Pr and $Y_3Al_5O_{12}$:Pr with different dopant concentrations, and $(Gd,Y)_3Al_2Ga_3O_{12}$:Ce garnets, and $(Lu,Gd)_2SiO_5$:Ce silicates with different host compositions was also investigated and discussed. We have found that the scintillators with high α/γ ratio show good proportionality of light yield down to 32 keV and better intrinsic resolution at 32 and 662 keV γ rays. Therefore, the α/γ ratio can be used to characterizing the non-proportionality of light yield and degree of scintillation light quenching in scintillators.

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Investigation the thermally stimulated luminescence of a lithium sulfate crystal

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Radiation-stimulated processes were previously studied in crystals of potassium sulfate and in complex lithium-potassium sulfate, activated by various ions. Crystals of lithium sulfate belong to the group of alkali metal sulfates. Consequently, it can be expected the presence of similarity in radiation-stimulated processes in these compounds. The presence of impurity ions can substantially change the processes of accumulation and recombination of radiation defects. Lithium sulphate, grown from an aqueous solution, is a crystal hydrate, and therefore it is possible to study the role of water and its effect on radiation processes in sulfates. Under the influence of ionizing radiation, radiolysis of water molecules can occur, whose products can substantially change the course of radiation-stimulated processes in the crystal. The experimental curves of TSL for monohydrate and dehydrated lithium sulfate are investigated. The exposure dose of the crystals was 200 kGy. In lithium sulfate monohydrate in the temperature range 80-300 K there are two main peaks of recombination luminescence with maxima at 100 K and 130 K. The observed thermally stimulated luminescence is associated with the appearance of radiation defects, since there is no luminescence in the unchanged samples in this temperature range. Significant qualitative changes in recombination processes as a result of heat treatment of the lithium sulfate crystal are explained by the fact that a peak of thermally stimulated recombination luminescence is observed in mono- and dehydrated samples at the same temperature. Therefore, the changes in the TSL curves observed in the work can be related to the change in the chemical composition of the crystals under study upon heating, i.e. with the presence or absence of molecules of crystalline water. The disappearance of the peak of recombination luminescence with a maximum at 100K after heat treatment of the sample can be explained by a change in the elemental composition of the compound. It can be argued that recombination processes associated with radiolysis products of crystalline water are responsible for this peak of TSL, and recombination of defects in the sulphate subsystem is responsible for the peak of emission with a maximum at 130K. The processes of formation of radiation defects in lithium sulfate monohydrate essentially vary depending on the energy of the incident quanta.

Investigation of the decay processes of the sulfate anion in potassium sulfate crystals

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One of the main tasks of modern solid-state physics is the development of methods for modifying their physical properties. Changes in the optical, electrophysical and mechanical properties of crystals are achieved by introducing substitutional impurities or by the action of ionizing radiation. The solution of these problems is impossible without systematic studies of model systems. For dielectric crystals, the role of model crystals is alkali-halide compounds (alkali halide compounds). Algebras are the simplest binary compound with the ionic character of the chemical bond. The object of research work is potassium sulfate. There are a number of studies on radiation-stimulated processes in potassium sulfate, a number of radiation defects have been established reliably. However, the literature data on the mechanisms of radiation defect formation and recombination processes are contradictory. The spectra of TSL of potassium sulfate crystals are studied in this work. A single peak at 200 K and a complex peak in the 280-300 K regions are observed on the TSL curve of the K_2SO_4 crystal. The spectral composition of the thermally stimulated luminescence was measured. The radiation spectra measured at a temperature of 190 K, at 270 K and 310 K are identical. The radiation has the form of a single band with a maximum at 3.1 eV. The strip is asymmetric. The second maximum can be identified in the region of 2.6 eV. The independence of the spectral composition of thermally stimulated radiation, which has all the features of recombination luminescence from temperature, presupposes the existence of a dominant recombination process for all the observed TSL peaks in the temperature region under study. The results obtained make it possible to conclude that the main channels of decay of the anion under study are associated with a change in its charge state or bimolecular reactions. This is because of the decays of the sulfate anion from the ground or excited electronic state have significant energy barriers and cannot be realized due to impact mechanisms by electrons that arise when irradiated with X-rays.

Nonequilibrium carrier absorption in cerium-doped LSO and LYSO scintillators

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Cerium-doped lutetium oxyorthosilicate (Lu_2SiO_5, LSO) is used in in positron emission tomography (PET) and is becoming increasingly attractive for high energy or nuclear physics experiments. Substitution of part of lutetium by yttrium in LYSO:Ce ($Lu_{2(1-x)}Y_{2x}SiO_5$) enables lowering the price of the crystal, though at the expense of lower density and effective atomic number. Due to their fast response to short-pulse excitation, both LSO and LYSO are considered for the barrel timing layer upgrade of the compact muon solenoid experiment at CERN.

Our study was targeted at the study of nonequilibrium carrier dynamics of importance for the fast luminescencce response of LSO and LYSO crystals. Optical pump and probe technique was exploited. A Yb:KGW laser emitting at 1030 nm was used as the primary light source. The major part of the laser output was used for the pump beam equipped with the wavelength converters to resonantly excite the cerium ions or by shallow traps near the bottom of the conduction band, while another part of the output was used to produce a white light continuum (in the range from 1.3 to 2.7 eV) used to probe the induced absorption at the delay, which was accomplished by optomechanical delay line.

In the wide spectrum of nonlinear absorption, the regions reflecting the density of free carriers and the population of trapping centers and radiative Ce level were identified. The absorption of the trapped carriers was selected as an indicator of the influence of the traps on the rise time of luminescence response. At direct excitation of cerium ions, the kinetics of the rise of the nonlinear absorption due to the excited Ce centers in LSO and LYSO crystals is identical, but the signal decays at a slower rate for the LYSO crystal. When pumped by 5.91-eV photons, LYSO:Ce initially shows the same rise time as LSO:Ce, however, exhibits a second, significantly slower rise component at the probe energies in the vicinity of 2.15 eV. We atribute this second component to traping of non-equilibrium charge carriers, which is expected to be stronger in a mixed crystal LYSO due to intrinsic composition disorder and, probably, due to additional defect-related trapping centers. We summarize our study by proposing a figure of merit to characterize the suitability of Ce-doped LSO and LYSO single crystals for fast radiation detectors.

Optical Absorption, Photoluminescence and Scintillation Properties of Ce-doped (Pb,Gd)3(Al,Ga)5O12 Epitaxial Films Grown From Pb- or Bi-Containing Melt Solutions

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The epitaxial garnet films attract attention because of their excellent scintillation properties. The films can be grown from different supercooled melt solutions such as PbO-B_2O_3 [1], Bi_2O_3-B_2O_3[2] or BaO-B_2O_3-BaF_2 [3]. Here we report the results of the study of the optical absorption, photoluminescence and scintillation properties of Ce:$(Pb,Gd)_3(Al,Ga)_5O_{12}$ and Ce:$(Bi,Gd)_3Ga_5O_{12}$ epitaxial films. Photoluminescence spectra of Ce:$(Pb,Gd)_3(Al,Ga)_5O_{12}$ films are characterized by a broad non-elementary band peaking at 532 nm (2.33 eV) which corresponds to the radiative 5d-4f transition within the Ce^{3+} ions. The pulsed cathodoluminescence yield of the most intensive $Pb_{0.01}Ce_{0.02}Gd_{2.97}Al_{3.13}Ga_{1.87}O_{12}$film was around 43100 photons/MeV and scintillation light yield was around 20000 photons/MeV under excitation from ^{133} Ba source. The pulsed cathodoluminescence decay times of this film were 1.8 (1%), 24 (25%), and 60 ns (74%) and scintillation decay times were 3.9 (7%), and 43.6 ns (93%). In the Ce:$(Bi,Gd)_3Ga_5O_{12}$films the 480 nm (2.58 eV) emission band with excitation maximum at 300 nm (4.13 eV) was observed and ascribed to Bi^{3+} centers. Also the emission bands at 850 nm (1.46 eV) under excitation at 337 nm (3.68 eV) and at 350 nm (3.54 eV) were observed in the Ce:$(Bi,Gd)_3Ga_5O_{12}$and $(Bi,Gd)_3Ga_5O_{12}$films. The origin of these bands is discussed.

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Modelling X-ray excited luminescence and afterglow behavior for complex garnets with kinetic equations

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Complex garnets are prominent materials for scintillator applications in medical imaging systems. One of the key application requirements to garnets is the time performance of their scintillation flash, in which secondary components and slow tails appear mainly due to trapping of charge carriers by anti-site [1] and impurity-related defects [2].

The traps influence on charge carrier transport is usually investigated with TSL and afterglow measurements. The shape of the TSL and afterglow curves is also taken into account for the analysis of the experiments. Symmetric TSL peaks and $1/t^2$-hyperbolic afterglow is usually considered to be a sign of dominant re-trapping of charge carriers [3]. However, the model of trap levels distribution can also be used to successfully describe symmetric TSL peaks [4] and hyperbolic afterglow curves [5]. We have recently found out that fits with both second order kinetics model for discrete trap levels and first order kinetics model for distribution of traps show good agreement with experimental TSL and afterglow curves for garnets.

In this work we investigate which of the two physical models actually takes place during the transport stage of scintillation process in garnets. We have constructed a system of kinetic equations for populations of localized on trapping centers and delocalized charge carriers with and without irradiation in the scintillation volume. The values for populations of each state and cross-section for the processes (represented in form of rates) are calibrated to fit not only experimental afterglow and TSL glow curves but also the dependence of X-ray excited luminescence on irradiation dose. Based on the best fits of the equation parameters to experimental data the presence of trap levels distribution in garnets is discussed.

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Luminescence and scintillation properties of GdxLu3-xAl5O12:Ce single crystals

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The luminescence and scintillation properties of $Gd_xLu_{3-x}Al_5O_{12}$:Ce (x = 1 - 2.25) single crystals are presented. The crystals were grown by micro-pulling down method. The Ce^{3+} $5d_1$ - 4f luminescence band was red-shifted with increasing Gd content due to an increase in the crystal field splitting of the 5d levels [1]. The Gd^{3+} - Ce^{3+} energy transfer was evidenced by photoluminescence excitation spectra of Ce^{3+} emission [2]. The light yield (LY) measurements were performed under excitation with α - and γ - rays, and its LY ratio (α/ γ ratio) was estimated. Under excitation with 662 keV γ rays, the LY value increases with increasing Gd content, and $Gd_{2.25}Lu_{0.75}Al_5O_{12}$:Ce crystal exhibits LY value of 12,800 photons/MeV. The dependence of LY value on an amplifier shaping time was measured to investigate the contribution of slow component in the scintillation pulse [3]. It was found that a relative content of slow component is reduced with increasing Gd content.

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Luminescence Properties of β-Ga_2O_3 Crystals Activated with Various Ions

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β-Ga_2O_3, which is the most stable form from five different modifications of gallium oxide, provides a prospective host for activation with different ions with a view to semiconductor scintillator applications [1-4]. In this Communication some important luminescence properties of Czochralski-grown β-Ga_2O_3 crystals [5], either pure or activated with diverse ions such as cerium, magnesium, chromium, silicon and tin, will be discussed. The results of measurements of radioluminescence and photoluminescence spectra, both as functions of temperature, as well as absorption spectra and low temperature thermoluminescence, performed on the above-mentioned samples, will be compared, monitoring the influence of the presence of activator ions. The shown absorption, radio- and photoluminescence spectra will be analyzed in order to identify all the observed lines and/or bands. Finally, the parameters of the traps detected via thermoluminescence studies will be determined by decompositions of the recorded glow curves.

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Luminescence and scintillation properties of Ca^{2+}-doped $(Lu_{1.66}Gd_{0.34})SiO_5$:Ce single crystal

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Luminescence and scintillation properties of Ca^{2+}-doped $(Lu_{1.66}Gd_{0.34})SiO_5$:Ce (LGSO:Ce,Ca) single crystal are presented and compared to $(Lu_{0.80}Gd_{1.20})SiO_5$:Ce (LGSO:Ce) one. Luminescence spectra, light yield (LY), energy resolution and scintillation decay were measured. At 662 keV γ-rays, the LGSO:Ce,Ca shows light yield (LY) of 25,600 photons/MeV and energy resolution of 9.3±0.5%, while the values of 20,200 photons/MeV and 6.0±0.3% are obtained for LGSO:Ce. The scintillation decay time with relative intensity of 18 ns(12%) + 42 ns(88%) was measured for LGSO:Ce,Ca, which is faster than that of 34(39%) +165(61%) for LGSO:Ce. The coincidence time resolution was measured in coincidence experiment with a fast BaF_2 detector [2]. The total mass attenuation coefficients at 60 and 662 keV γ - rays were also determined [3].

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Dependence of the Ce3+ - related photo- and thermally stimulated luminescence characteristics on the Mg2+ content in the single crystals and epitaxial films of Gd3(Ga,Al)5O12:Ce,Mg

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Single crystals of $Gd_3(Ga,Al)_5O_{12}$:Ce (GAGG:Ce) are intensively studied as promising scintillator materials for medical imaging due to their extremely high light yield, excellent energy resolution, high density, fast scintillation response, high radiation stability, and high hardness [1]. A considerable improvement of scintillation characteristics has been achieved by the co-doping of GAGG:Ce crystals with Mg^{2+} ions. A positive influence of Mg^{2+} on the characteristics of GAGG:Ce is mainly caused by the formation of Ce^{4+} ions as effective electron traps which successfully compete with intrinsic electron traps in the crystal lattice of GAGG [2].

In this work, photo- and thermally stimulated luminescence of GAGG:Ce crystals and epitaxial films with different Mg contents are investigated in the 77-500 K temperature range under excitation in the 4f-$5d_1$ and 4f-$5d_2$ absorption bands of Ce^{3+}. Influence of Mg^{2+} ions on the photoluminescence intensity, spectrum, decay kinetics, temperature dependence of the photoluminescence intensity, and the activation energy of the luminescence thermal quenching is observed. The presence in GAGG:Ce,Mg of Ce^{3+} ions perturbed by the neighboring Mg^{2+} ions is shown. Nonradiative transitions from the lowest-energy excited $5d_1$ level to the ground 4f state of the perturbed Ce^{3+} centers are suggested to explain the reduction of the Ce^{3+} luminescence output with the increasing Mg content. Co-doping with Mg^{2+} is shown to result in a drastic reduction of the afterglow and thermally stimulated luminescence (up to three orders of magnitude) and in a strong shortening of the afterglow decay kinetics. It influences also defects creation spectra and the activation energy of the photostimulated defects creation. The Mg^{2+}-induced changes in the characteristics of GAGG:Ce,Mg crystals and epitaxial films are found to be different. Possible reasons of these differences are discussed.

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Tuesday, 11 September 2018, 09:00-09:30 K4-Tue

Radiation-Induced Structural Defects and Their Thermal Annealing in Magnesium Aluminate Spinel

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Insufficient resistance against prolonged irradiation is a serious limitation for the use of wide-gap materials in the environment of the future fusion reactors (DEMO, PROTO, etc.). Presently, the search for wide-gap materials with optical/diagnostics window capabilities and a high tolerance to neutron radiation in fusion devices is an urgent task in the research programs of the EUROfusion consortium. $MgAl_2O_4$ spinel crystals and ceramics exhibit high resistance against heavy irradiation, very little swelling and belong to attractive candidates for window materials. It is generally accepted that a high radiation tolerance of $MgAl_2O_4$ is explained by the efficient recombination of interstitial-vacancy pairs formed during irradiation. Such self-healing process is stimulated by a huge concentration of "native" vacancies in the cation sublattice (empty cages) of a normal spinel and cation swapping between tetrahedral and octahedral sites. The swapping results in the formation of antisite defects $-$ Mg|$_{Al}$ or Al|$_{Mg}$$-$ i.e. Al^{3+} or Mg^{2+} in a "wrong" cation position. A comparative study of radiation damage caused by MeV fission neutrons n, GeV swift heavy ions and 100-keV protons in $MgAl_2O_4$ with different stoichiometry has been performed. The damage was analyzed using the methods of electron paramagnetic resonance, induced optical absorption (IOA, region of 1.4-9 eV), cathodo- and photo-luminescence and thermoactivation spectroscopy (up to 1200 K).

The analysis of the EPR signal angular dependencies at different microwave power after each preheating to T_i allowed to reveal a number of novel radiation defects. These defects possess positive g-factor shift and are ascribed to the holes localized at regular O^{2-} nearby negatively charged defects (Al and Mg vacancies or antisite defects) in 1:1 and 1:2.5 Mg-Al spinel samples. The pulse annealing of the EPR signal of radiation defects was compared to that of IOA in the same crystals in order to find correlation between intrinsic defects and relevant IOA bands. The nature and microstructure of the revealed radiation defects in Mg-Al spinel is considered and the tentative scenario of the annealing process of n-induced defects (hole-type and complementary electron F-type ones) is proposed. After irreversible annealing of n-induced hole centers and an additional x-irradiation, some other EPR-active centers were detected in both Mg-Al spinel samples. These centers are formed via hole trapping at different as-grown complex defects and their reversible decay is caused by the thermal release of holes. Optical characteristics of antisite defects, revealed earlier in YAG and LuAG, were determined for spinel ceramics in optical absorption and luminescence excitation spectra. The accumulation of proton-induced radiation damage (fluence varies from 10^{15} to $5\text{x}10^{17}$ cm^{-2}) was analyzed for spinel ceramics by means of IOA and cathodo-luminescence. The joint contribution of the universal knock-on mechanism and several nonimpact mechanisms (related to the decay of electronic excitations) to radiation damage of wide-gap materials is considered.

Tuesday, 11 September 2018, 09:30-09:45 O15-Tue

About the nature and distribution of defects in crystalline cubic boron nitride wide band-gap semiconductor

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Cubic boron nitride (cBN) with zinc blende structure is a synthetic wide band-gap (6.25eV) semiconductor comparable to diamond in thermo-mechanical properties, which can be relatively easily *p*- and *n*-doped resulting in *p-n* junctions and UV LED's operating at T=900K, without significant changes in their electrical and optical parameters [1,2]. The presence of radiation induced emission bands and its high radiation resistance makes cBN a very interesting optoelectronic and radiation detecting material in extreme conditions [3]. However, any further use in such applications requires understanding the lattice defects properties. Previous investigations by Electron Spin Resonance (ESR) on as-grown nominally pure cBN crystals resulted in the observation of paramagnetic point defects with spectra properties suggesting their aggregation due to a non-uniform distribution of growth impurities [4]. In an effort to identify the nature and distribution of impurities involved in the paramagnetism of the nominally pure crystalline cBN we performed investigations by multifrequency ESR, optical absorption and photoluminescence spectroscopy on crystalline cBN powder samples consisting of amber and dark colored large size (< 200 micron) crystallites. Microstructural investigations were also conducted by X-ray diffraction, analytical high resolution scanning transmission electron microscopy, scanning electron microscopy and electron dispersive X-ray analysis. The results of the correlated analysis of the above mentioned investigations shall be presented.

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Electron transfer between heterogeneous lanthanides in BaF_2 crystals

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For the first time the photo transfer of an electron from the Eu^{2+} ion to the Sm^{3+} ion in crystals of alkaline-earth fluorides CaF_2, SrF_2, BaF_2 was studied by Feofilov [1]. The reverse thermal transition occurred after heating to 400-600 C with the restoration of the initial absorption spectrum [1]. The thermal bleaching of induced absorption bands in Sm^{2+}-RE^{3+} ion pairs (where RE is Nd, Sm, Dy, Er, Ho) during linear heating was studied by Arkhangelskaya in CaF_2 and SrF_2 crystals. The thermal ionization potentials of a number of divalent lanthanides have been determined from the thermobleaching curves [2]. For noninteracting lanthanides, the ionization potentials are equal to the energy levels of these ions relative to the bottom of the conduction band. Knowledge of the position of the lanthanide levels in the crystal band scheme is extremely useful for understanding many phenomena such as thermoluminescence, scintillation mechanisms, persistent luminescence, etc. [3].

Crystals BaF_2 doubly doped by Re_1F_3 and Re_2F_3 in equal concentrations 0.01, 0.03, 0.1 mol. % were grown. As a rule both lanthanides inroduced into crystal in trivalent form. For the transformation acceptors into a divalent form, an additive coloration procedure was used. The electron transfer was observed by a sequential change in the absorption bands in crystals with Eu, Yb, Sm acceptors and Nd, Sm, Dy, Ho, Er, Tm, Yb donors. The largest transfer is measured in crystals with an acceptor Yb^{2+}. When the photobleached crystals were heated, the bands of divalent donors decreased and the bands of divalent acceptors were restored. The half-life temperatures of the donor centers Ho, Nd, Dy, Tm, Sm, Yb were 336, 373, 400, 515, 695, 823 K, respectively. The reverse conversion is accompanied by persistent luminescence and thermoluminescence. The thermobleaching curves of the donor absorption bands were described well by first-order kinetics. The experimental positions of the divalent lanthanide levels are directly proportional to the half-life temperature. The dimensionless Urbach constant [4] is 33,9. The processes in BaF_2 crystals during photobleaching and thermal reduction and also the comparison of the experimental and estimated [3] positions of the levels of divalent lanthanides are discussed.

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Spectral analysis of LiF:Mg,Cu,P detectors with different dopants concentration after ultra-high radiation doses

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The thermoluminescent phosphor based on lithium fluoride doped with magnesium, copper and phosphorus (LiF:Mg,Cu,P) is widely used as highly sensitive detector. The role of activators and influence of their concentration on thermoluminescent properties, including emission spectra, has been studied extensively in the past. It was established that the main dopants are magnesium and phosphorus, while copper seems to play indirect and subsidiary role. All these investigations however, were performed after irradiations with relatively low doses, i.e. doses which do not cause significant changes in the glow-curve shape.

In the year 2006 the high-temperature emission of LiF:Mg,Cu,P detectors irradiated with doses above 1 kGy was discovered and opened new possibility for ultra-high dose measurements [1]. The most important was finding of a new peak, named "peak B", occurring after doses above 50 kGy at temperatures exceeding 400°C. Peak B exhibits several peculiar features and enables dosimetric measurements of doses up to 1 MGy. The first studies of emission spectra of highly exposed (up to hundreds of kGy) LiF:Mg,Cu,P detectors revealed that a longwave emission appears at doses higher than 4 kGy, but at the peak "B" dose and temperature range, the wavelength of emission is nearly identical as for the standard main peak at 220°C [2]. Recently we started to study influence of dopants concentration on high-dose high-temperature thermoluminescence of LiF:Mg,Cu,P [3].

Presently we report results of investigations of the influence of dopant concentration on TL emission spectra after ultra-high doses of radiation. The amounts of dopants were varied from 0 up to 200% of standard content. The samples were irradiated with gamma-ray doses ranging from 1 kGy up to 1000 kGy. One of the interesting findings is that both magnesium and copper are necessary to obtain the typical high-dose TL signal with peak B. For the samples without copper, the spectrum for ultra-high dose is dominated by a longwave emission, peaked around 700 nm and extending beyond 900 nm. In the presentation a systematic analysis of the various parameters of TL glow-curves and TL emission spectra and their relationship with dopants concentrations and dose, will be discussed.

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Anomalous Quenching Factor for alpha particles in ZnSe crystals – is puzzle solved?

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The modern goals in physics of rare nuclear processes (like neutrinoless double beta decay search, or dark matter particles detection) constantly raise demands to detector techniques and require more powerful experimental tools. To effectively detect such elusive events the use of a detector with high efficiency and enhanced sensitivity is required. Cryogenic scintillating bolometers are among the most promising detectors used for the investigation of rare nuclear processes due to their excellent energy resolution and background rejection capabilities thanks to the simultaneous and independent, double readout of heat and scintillation light induced by particle interaction in the crystal.

It has been recently proposed to use the scintillating bolometers based on ZnSe scintillating crystals to search for neutrinoless double beta decay of ^{82}Se within the CUPID-0/ZnSe experiment (former LUCIFER). Despite ZnSe scintillators are well-known scintillating material, which are widely applied as detectors for X-rays and gamma rays, these crystals have one unique feature: alpha particles produce more light than electrons for the same deposited energy in the detector, i.e. Quenching Factor (QF) > 1. This behavior is in contrast to all other scintillators for which QF is less than 1. This phenomenon has not yet been properly explained whereas it is a very important for the detector performance.

Our efforts for finding a proper explanation for the observed anomaly, based on systematic analysis of dual-channel detection systems, like cryogenic noble gas TPC, ZnSe scintillating bolometers and Ge ionization bolometers are presented here. We believe that such study lead towards development of high sensitive detectors for next generation of low-background experiments, as well as to a wider application of ZnSe compound.

Non-radiation creation of complex centers in wide-gap oxide crystals

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It was shown in [1, 2] that upon the irradiation of anion-deficient corundum crystals (α-Al_2O_{3-d}) by moderate fast-electron fluences, it is possible to create complex aggregate centers of oxygen divacancy type (F_2) and interstitial aluminum type near the anion vacancy (Al_i). It has been recently found [3] that thermo-optical treatment (TOT), including ultraviolet irradiation and simultaneous heating of samples, allows to create one of the Al_i center types in α-Al_2O_{3-d}.

It is shown in this paper that the complex $F_2$and Al_i type centers are formed n anion-deficient crystals of corundum and beryllium oxide (BeO_{1-d}) under certain TOT regimes. These centers are similar to those created in α-Al_2O_3 and BeO under neutron irradiation [2, 4, 5]. It is important to note that thermal stability of the TOT-created complex centers is higher than that of similar neutron-induced centers. It is also established that the probability of their formation is related to the temperature of the TOO, the wavelength of the stimulating light, and the initial anionic deficiency manifested as F^+ and F centers (anion vacancies with one and two electrons, respectively).

To confirm the complex centers creation in α-Al_2O_{3-d} and BeO_{1-d} crystals, optical absorption (OA) and photoluminescence (PL) data at 4-300 K are presented. They are close at 300 K to those of neutron-irradiated α-Al_2O_3 and BeO samples. At low temperatures, the OA and PL bands of the complex centers TOT-created in α-Al_2O_{3-d} become highly structured and they reveal zero-phonon lines and phonon replicas. The observed fine vibronic structure is typical for complex Al_i-, F_2-type centers and it is similar to that observed in neutron-irradiated α-Al_2O_3 samples [2, 4, 6].

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New approach for the growth of scintillator crystals

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So far, the majority of the functional single crystalline materials including scintillator are fabricated as bulk crystals using the Czochralski (Cz) or Bridgeman (BS) methods. We need extensive machining process such as cutting, slicing, polishing and so on. Moreover, the atmosphere is limited due to Ir crucible, which is easily oxidized by oxygen (above 2 % of partial pressure) in high temperature. This low oxygen partial pressure induces the vacancies, which is the origin of slow component or non-radiative transition.

As far as we are using the present (CZ, BS) method, the process losses are not negligible. “Shaped crystal growth” can be the way to reduce the loss. In the market, Sapphire single crystals shaped as plates, rods, fibers are produced using the Edge-defined Film-fed Growth (EFG) method. As the temperature distribution of the liquid solid interface can be controlled as it uses the die, it is suitable not only single crystal, but also eutectics, which require highly homogeneous distribution [1,2,3]. One of the example is the submicron-diameter phase separated scintillator fibers (PSSFs) using the eutectic system. In PSSFs, the light emitted from the scintillator fibers is confined and transported along the fiber direction by a total reflection mode, so that high-resolution radiation imaging can be achieved. CsI/NaCl [2] and GAP/ α-Al_2O_3[3] have been reported as PSSFs.

In order to grow oxide bulk crystal with higher oxygen partial pressure, skull method is used to melt the chemicals and puller of CZ technology is used. The fusion these famous method allows us to grow high melting temperature oxides in air atmosphere (around 20% of oxygen partial pressure). This method contributes to bring various benefits such as following items; (1) No contamination from crucible (2) No limitation of atmosphere (3) No limitation of the melting temperature (4) Reduce the cost of fabrication of bulk crystals. The growth attempts of Ce:GAGG and Ce: La-GPS were carried out and the result will be shown in the presentation.

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Engineering of Scintillation Materials and complex phases crystals synthesis

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Saint-Gobain Crystals is actively working in the research of engineered (co-doped) inorganic scintillation materials recently proposed by the company on the markets and became available for the customers.

The particular attention is attributed to the synthesis and improvements of CLLB ($Cs_2LiLaBr_6$:Ce) - new industrial scintillation material for dual gamma and neutrons detection. The material possesses the intrinsic Pulse-Shape Discrimination (PSD) property and demonstrates good energy resolution better than 4.0% at 662 keV. The available size of detectors is up to 2"x4".

We are planning to share some of discovered solutions to overcome the difficulties of this crystalline composition synthesis.

Also we'll share on the properties of became recently available NAIL^{TM} (NaI:Tl:^{6}Li). The one is known as scintillation material with dual detection capability for gamma and neutrons with competitive cost. Material possesses a PSD capability with an exceptional value of Figure of Merit in terms of discrimination. The available size of detectors is up to 4"x4"x16".

The scintillation materials like Ce-doped $LaBr_3$ and LYSO are became classic and under intensive development since last 15 years. The last improvements through co-doping making Brillance-390S^{TM} ($LaBr_3$:Ce:Sr) crystals a champion with 2.2% energy resolution at 662 keV. This result are demonstrating for serial industrial 1.5"x1.5 detectors in scintiblocks assembling. The light yield is improved relatively to the referenced Brillance-380 and a new feature of PSD capability has been demonstrated. The last feature is permitting in particular to eliminate partly the contribution of intrinsic radioactive alpha background. The available size of detectors is up to 4"x10".

The main material for positron emission tomography (PET) applications is Ce-doped L(Y)SO. The engineered (LYSO:Ce:Ca) is still in the focus for various optimizations related to Ce activator and co-dopants concentrations to meet the requirements of improved timing properties (CRT -coincidence resolving time), energy resolution and light yield.

Scintillation Properties of Eu-doped $LiCaAlF_6$ and $LiSrAlF_6$ fluoride single crystals with improved Eu segregation

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Eu^{2+} doped $LiCaAlF_6$ and $LiSrAlF_6$ [Eu:LiCAF, Eu:LiSAF] single crystals have been investigated as a neutron scintillator for homeland security. The Eu:LiCAF and Eu:LiSAF single crystals indicated high light yield, 30,000 photons/neutron, compared to present neutron scintillators. However, the segregation coefficient, k_{eff}, of Eu^{2+} ion in the Eu:LiCAF and Eu:LiSAF single crystals is extremely small, k_{eff} = 0.02 0.03, and the small segregation coefficient generated inhomogeneity in the bulk single crystals and decreased the yield rate of bulk single crystals. Therefore, we developed Eu:LiCAF and Eu:LiSAF single crystals using Al metal as a starting material and the small segregation coefficients were improved due to the chemical reaction between Al metal and EuF3 starting materials.[1] In this study, the scintillation properties were investigated to reveal the effects of the segregation coefficient improvement on the scintillation properties of Eu:LiCAF and Eu:LiSAF single crystals.

$Li(Ca_{1-x}Eu_x)(Al^F{}_{1-y}Al^M{}_y)F_6$ and $Li(Sr_{1-x}Eu_x)(Al^F{}_{1-y}Al^M{}_y)F_6$ with x = 0.005 0.03 and y = 0, 0.01 [Eu,Al^M:LiCAF and Eu,Al^M:LiSAF] were grown by the micro-pulling-down (μ-PD) method. In the chemical formula, Al^M and Al^F are Al elements derived from AlF_3 and Al metal, respectively. Rectangular specimens with the thickness of 1 mm were obtained from the grown crystals and they were polished for measurements of optical and scintillation properties.

In the radioluminescence spectra of the polished Eu,Al^M:LiCAF and Eu,Al^M:LiSAF specimens under α-ray irradiation, emission peaks were observed around 375 and 380 nm, respectively. The emissions were attributable to the 5d-4f transition of Eu^{2+} ion. The wavelength of emission peaks systematically increased with increasing Eu concentration due to the increase of absorption by Eu^{2+} ion. Light yield of Eu,Al^M:LiSAF crystals under thermal neutron irradiation increased with an increase of Eu concentration and the specimen with x = 0.02 indicated the maximum light yield, 10,000 photon/neutron. The decay times under thermal neutron irradiation systematically increased with an increase of Eu concentration and it is the same trend as for the Eu:LiSAF single crystals grown without Al metal. [1] Y. Yokota, A. Yoshikawa, et al., *AIP advances*, 7 125312 (2017)

Applications of amorphous track structure models for correction of ionization quenching in organic scintillators exposed to ion beams

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Organic plastic scintillators are attractive for particle therapy dosimetry due to their prompt response and good water-equivalence. However, scintillators exhibit a signal reduction, termed ionization quenching, as they are exposed to radiation with a high linear energy transfer (LET). The semi-empirical Birks model [1] is widely used in solid state dosimetry to correct the signal for the quenching effect but is known to break down even for low-energy photon beams. Moreover, the Birks model erroneously gives the same correction factor for two ions with the same LET, but different atomic number, which contradicts experimental observations.

We propose a new method—based on amorphous track structure theory—to correct for ionization quenching in organic scintillators exposed to ions. The kinetics of excited states in an organic scintillator can be modeled by a general equation derived by Blanc [2], where the excited states are allowed to migrate, fluoresce and quench. Birks model is a solution to the Blanc equation only if several terms are neglected while the radial energy deposition distribution is unaccounted for. We apply track structure theories to distribute the excited states in accordance with energy deposition by secondary electrons. The luminescence is then calculated as governed by the Blanc model.

The ionization quenching is computed from first principle relying only on standard scintillator properties as the decay time, the light yield, and the density. Consequently, the ionization quenching correction factors may be calculated theoretically for any ion and plastic scintillator, in contrast to the Birks model which relies on extensive experimental measurements. The computed quenching correction factors are validated against experimental measurements for different plastic scintillators. An investigation of the temporal structure of ionization quenching indicates that quenching occurs at a time scale less than the characteristic decay time of the scintillator.

An algorithm, which readily computes quenching correction factors from first principles is presented as the open source software package `ExcitonQuenching`. The software is available for download [3] and provides a better understanding of ionization quenching, an extension to the Birks model as well as an efficient way to correct ionization quenching.

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Development of red-orange-emitting halide scintillator for single photon counting

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Cs_2HfCl_6 (CHC) is an attractive halide scintillators with a high light output of up to 54,000 photons/MeV [1]. Since the light output is expected to improve by decreasing the band-gap energy, we focused on Cs_2HfI_6 (CHI) with smaller band-gap energy than CHC [2] and succeeded in the growth of the non-doped CHI single crystal, where CHI has a scintillation emission wavelength of around 650 nm and high light output of up to 70,000 photons/MeV [3]. Moreover, the scintillation decay time was estimated to be 2.55 μs. CHI could be a promising red-orange emitting scintillator available for single photon counting when coupled with a photodetector. The origin of luminescence and optical properties have been still unclear. In this work, we performed further study of the optical properties of CHI.

Absorption spectra were measured using a CHI single crystalline specimen at room temperature and 8K in the synchrotron facility (Ultraviolet Synchrotron Orbital Radiation Facility III, UVSOR-III) at the Institute for Molecular Science in Okazaki, Japan. Photoluminescence excitation and photoluminescence emission spectra were measured with a spectrometer and integration sphere. In addition, the photoluminescence decay time was evaluated.

The absorption spectra showed that CHI has an absorption edge around 480 nm, which is the reason of the orange color of the CHI crystal. At 8K, the absorption edge shifted towards to 460 nm due to the suppression of lattice vibrations. At room temperature, the photoluminescence emission peak was observed around 640 nm when the sample was excited by 480-nm photons, and the photoluminescence decay constant at 640-nm-emission and 480-nm-excitation was 2.03 μs. Using the integration sphere, the inner quantum yield reached approximately 70%. Moreover, in this presentation, the temperature dependence of the photoluminescence intensity of CHI to evaluate the origin of luminescence will be presented.

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Fabrication and performance optimization of Pr:Lu3Al5O12 ceramic scintillators

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Pr:$Lu_3Al_5O_{12}$(LuAG) was pointed out as a promising fast scintillator because of its short decay time of about 20 ns and high density of about 6.7g/cm^3 [1, 2]. These make it can be potentially used in the field of high energy physics, medical imaging. Compared with the single crystal, Pr:LuAG ceramics have advantages in uniformly doping, low price and lower preparation temperature which may bring a superior scintillation properties because of fewer anti-site defects.

In this work, polycrystalline Pr:LuAG transparent ceramics were fabricated by solid-state reaction and vacuum sintering using 100 ppm MgO as the sintering aid. The as-sintered Mg,Pr:LuAG ceramic sample shows a transmittance of 71.5 % at 310 nm. However, increasing Pr^{4+} by high temperature air annealing process seriously deteriorates the scintillation properties because of the self-absorption [3]. In order to avoid being influenced by the sintering additives, we prepared Pr:LuAG ceramics with different excess of Lu (-2 at% - 3 at%) without any sintering aids. Transparent ceramics can be obtained while the excess of Lu is more than 1at%. LuAG transparent ceramics with different doping concentration were prepared. A high doping level was found to be able to greatly suppress the slow content in the scintillation decay. To further optimize the scintillation properties of the Pr:LuAG transparent ceramics, 25% Y admixture was introduced, the effect of “band-gap engineering” works in Pr:LuYAG ceramics and greatly eliminates the defect-induced host luminescence. The light yield of Pr:LuYAG ceramics with 25% Y is found to be 24400 ph/MeV with 1.0 μs shaping time, which is 20% higher than the value obtained for Y-free Pr:LuAG ceramics [4].

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Latest trends in medical dosimetry using fiber-optic luminescent instrumentation

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Important tasks in medical dosimetry are to establish the absorbed dose to water under reference conditions or in patients undergoing radiotherapy. Several detector systems are available for these purposes, and although gas-filled ionization chambers are the most commonly used detector, these detectors are not ideal in all cases due to their relative large size and their perturbation of the radiation field. Fiber-coupled lumininescent detectors represent an alternative technology that has been subject to much research and development over the last two decades. Their key features are the small size of the detector (characteristic dimensions are typically 1 mm or smaller) and the minimal perturbation caused by the detector, especially for all-plastic probe designs. Basically, fiber-coupled lumininescent detector systems consist of four elements: (i) a sample of lumininescent material such as an organic plastic scintillator, an inorganic crystal such as Al_2O_3:C or silica fibers doped with, for example, Ce, Cu or Eu, (ii) an optical light guide of quartz or plastic (typically 15 m long), (iii) readout instrumentation based on photodiodes, photomultiplier tubes or cameras, and (iv) protocols for calibration and data processing. The systems typically provide online readout. An important challenge is to be able to discriminate between the detector signal and the light generated in the fiber cable during irradiation (often a combination of Cerenkov light and fluorescence). Another challenge is that the light yield (i.e. the signal produced per energy absorbed in the detector material) is not independent of the beam quality. These issues have implications for the uncertainty and traceability of the measurements. The purpose of this presentation is to provide an overview of this field with highlights of the most promising and recent applications such as in vivo dosimetry during special medical procedures and small-field dosimetry in megavoltage photon beams from medical linear accelerators.

Development of a PET module with DOI and timing capabilities

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For a PET scanner, high spatial resolution and sensitivity are fundamental in order to ensure early stage detection of cancer. Depth Of Interaction (DOI) is an important quantity in small PET scanners, where it helps to reduce parallax error, but also in whole-body PET machines, because is useful to improve Coincidence Time Resolution (CTR).

The module we developed is made of a matrix of 16*16 LYSO crystals with single side readout (a Hamamatsu array of 4*4 MPPCs) and allows light recirculation thanks to a reflector on the side of the matrix opposite to the photodetector. The DOI coordinate is extracted as the ratio between the light detected by the single MPPC coupled to the crystal hit and all the light collected by the 16 MPPC channels. The DOI resolution obtained with this method is of 3mm FWHM and the energy resolution of the module is 10% FWHM energy resolution at 511 keV.

The reconstruction abilities of this module were preliminarily tested using a pair of identical detectors and a point source of 1mm. The source was rotated around the midpoint between the detectors in order to simulate a full ring of crystals. The spatial resolution achieved is of the order of 1.5 mm FWHM in all directions.

In order to improve time resolution of the module, the idea is to use the DOI information to correct for the time spread caused by the different interaction coordinates of the gamma photons along the main axis of the crystal pixel. Exploiting the correlation between DOI and time of arrival of the optical photons produced after a scintillation event to the photodetector, it is possible to take into account this delay and therefore improve CTR.

Using a small tagging crystal in coincidence with our matrix and a Na22 source, the CTR of the module was estimated to be around 360 ps FWHM without DOI correction, and 240 ps with the DOI correction.

Scintillation Properties of Y-admixed $Gd_2Si_2O_7$ doped with Ce

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Ce:(Gd, La)$_2$Si$_2$O$_7$ (Ce:La-GPS) has a good light output of around 40,000 photons/MeV, full-width-at-half-maximum (FWHM) energy resolution of better than 5-7% at 662 keV and scintillation decay time (primary component) of approximately 40-80 ns[1]. Additionally, even up to 150°C, the light output keeps its value around 40,000 photons/MeV[1], and thus the energy separation (E_o) between the bottom of the conduction band and the lowest 5d state of Ce^{3+} is expected to be larger than in the other scintillators. To obtain novel materials with high light outputs even at high temperature, Horiai et al., investigated Y and La-admix Ce:GPS which was expected to have wider bandgap-energy and larger E_o than Y-free Ce:La-GPS [2]. 5mol% Y-admixed Ce:La-GPS scintillator can keep higher light output when compared with Y-free Ce:La-GPS scintillator. On the other hand, both emission wavelengths overlapped.

In this paper, we investigated scintillation properties for "La-free" and "Y-admixed" Ce:GPS (Ce:Y-GPS) grown by Floating zone method in order to show the effect of La and Y-admixture on the bandgap and emission spectra. The results showed that Ce:Y-GPS had an emission peak, originating from 5d-4f transition of Ce^{3+}, at shorter wavelength region around 355 nm when compared to Ce:La-GPS (approximately 370 nm). Thus, we found that the crystal field of Ce:Y-GPS was changed compared to Ce:La-GPS and Y-admixed Ce:La-GPS. Moreover, Ce:Y-GPS had a light output of 48,000 ± 3,000 photons/MeV and the primary decay time components of 42 ±1 ns.

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Tuesday, 11 September 2018, 15:30-15:45 O27-Tue

Eu^{2+}-doped $ARES_2$ sulfides – novel multifunctional optical materials

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Eu^{2+}-doped ternary sulfide of $KLuS_2$ composition was investigated recently as potentially interesting phosphor for gamma and X-ray radiation detection, especially due to its rather high density (4.71 g/cm^3) and effective atomic number (59), suitably positioned emission at 520 nm, yet reasonably fast photoluminescence decay at room temperature (decay time 450 ns), extra-ordinarily high light yield (> 35000 ph/MeV for 0.05% Eu^{2+} concentration) and favourable high temperature stability of Eu^{2+} emission [1,2]. When Na^+ ions are incorporated into the $KLuS_2$ structure, Eu^{2+}-doped $K_xNa_{1-x}LuS_2$ solid solution is created and such composition possesses unique photoluminescence properties such as broad emission tunability range over visible part of the spectrum, which makes it ideal for solid state white LED lighting [3-4]. In presented work, various compositions of Eu^{2+}-doped sulfides of general formula $ARES_2$ (A is any combination of alkali metals Cs, Rb, K, Na, Li and RE is any combination of La, Gd, Lu and Y) similar to $KLuS_2$ were synthesized in the form of crystalline hexagonal platelets by inorganic chemical reaction under the flow of H_2S and further characterized by means of X-ray diffraction, X-ray excited fluorescence and time-resolved photoluminescence spectroscopy. Special attention is given to photoluminescence excitation and emission spectra and their temperature dependences. CIE xy-coordinates are calculated to compare effects of different elements concentrations in $ARES_2$ compounds on resulting spectrum. The application potential of mentioned compounds in the field of white LED solid state lighting or X-ray phosphors are thoroughly discussed.

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Luminescence and scintillation characterization of PbMoO4 scintillation crystal for neutrinoless double beta decay search

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The AMoRE (Advanced Molybdenum based Rare Process Experiment) has been actively searching for the neutrinoless double beta (0 $\upsilon\beta\beta$) decay in ^{100}Mo using ^{40}Ca^{100}MoO$_4$ (CMO) as cryogenic scintillator. However, because of purification limitation, the CMO crystal causes unavoidable background in the energy region of interest, therefore the R&D for new Mo-based scintillation crystal with low intrinsic radioactivity and high light yield for the next phase of AMoRE experiment is ongoing. The feasibility of PbMoO$_4$ (PMO) crystal for 0 $\upsilon\beta\beta$ decay search is examined with the excitation of UV, α-, γ-, and β-rays over the temperature range of 10-300 K. The luminescence and scintillation major decay time are found to be 20, 18 and 28 μs under 280 nm, 662 keV γ-rays and 5.5 MeV α-rays excitation respectively, at 10 K. The luminescence light yield is estimated to be 11% as compared with that measured for CMO crystal at 10 K. The light yield at 10 K under 662 keV γ-rays excitation is estimated to be 8,000 photons/MeV with 66 μs time window in comparison with BGO crystal. An enhancement in light yield is found and estimated to be 5.5 times at 10 K as that measured at 175 K under α-rays excitation. The scintillation light yield under β-rays excitation through continuous measurement is found to be 109% of the CMO at 10 K. The thermo-stimulated luminescence is studied under X-ray excitation in the temperature range of 10-300 K. The temperature dependence of luminescence and scintillation response for PMO crystal and its potential for 0 $\upsilon\beta\beta$ decay search will be discussed.

Ceramic scintillators with potential for neutron detection

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Scintillators for various applications often have different specific requirements. For soft gamma quanta detection for computed tomography - minimal afterglow, for annihilation gamma quanta detection for positron emission tomography - high stopping power, transparency and fast kinetics, for neutron detection - incorporation of n-sensitive isotopes (^{6}Li, ^{157}Gd, ^{10}B). Moreover, different applications could allow different material costs. It is attractive to develop a material or materials family, which could fit a wide range of applications, which are technologically closely related - to decrease production costs and which have likely physics - to allow their deep study. An actively developed family of multicomponent oxides with garnet structure is a candidate for this role.

In this work we report on progress done in research and development of ceramic scintillators based on garnet structure oxides and their application to neutron detection. Ceramics form of material gives it flexibility in composition, allowing tuning of the luminescence parameters. At the same time translucent ceramics lacks the perfect transparency of single crystals, but could be obtained using overall cheaper technologies.

Initial powders were obtained using coprecipitation approach, then compacted and sintered in air or vacuum, resulting in translucent ceramic plates. A variety of compositions in $(Gd,RE)_3(Ga,Al)_5O_{12}$:Ce system were obtained and their photoluminescence, scintillation light yield and kinetics were probed. Light scattering translucent ceramic samples demonstrate, nevertheless, reasonable detector properties. Scintillation kinetics and light yield systematic dependence on garnet host composition were studied. Neutron detection properties of Gd-containing garnet ceramics were demonstrated.

Investigation of the helper's dose during veterinary X-ray inspection

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In Taiwan, the number of veterinary hospital is growing rapidly in nearly two decades. For some health reasons, the pet is usually sent to a veterinary hospital to perform the X-ray inspection. Due to the pet breeder needs to accompany the pet inside the X-ray room during the X-ray inspection in most cases. The breeder or helper in the X-ray room is also exposed to the scattered X-ray radiation. Thereby, the purpose of this study is to investigate the exposed effective doses of the helpers inside the X-ray inspection room during general veterinary radiographic procedures. Over 200 veterinary hospitals were inspected on-site in this study. The doses were mainly measured using a plastic scintillation survey meter (Atomtex AT1121), and the thermoluminescent dosimeters (TLDs) were used in some cases. By means of setting the survey meter at the position of the pet breeder's (helper's) body which is assumed at a distance of 50cm from X-ray field center, and considering the conditions of wearing with/without lead apron respectively, the ambient dose is measured by the survey meter and then transfer into effective dose by considering the conversion factors suggested in ICRP 116 and EURADOS RP 106 report. Besides, Monte Carlo (MCNP) simulation of the dose distribution inside the X-ray inspection room was also conducted to compare with the results of the measured doses on site. Statistical analysis of investigating effective doses of the pet breeders staying inside the veterinary X-ray room to accompany the pet is presented in this work.

Performance Evaluation of depth-encoding absorber detectors for prompt-gamma Compton imaging in proton therapy

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Prompt-gamma Compton imaging (PGCC) is a potential method for real-time proton range verification. Usually scintillation detectors with thick, high Z crystals are chosen as Compton absorbers to get higher probability to absorb full energy of Compton scattered photons and to obtain higher detection efficiency. However, an absorber with the longer/thicker crystals will cause a Compton camera the worse spatial resolution, if the absorber is without depth-of-interaction (DOI) capability. Continuous DOI detectors are usually using LSO or LYSO scintillators with crystal length <20 mm for 0.511 MeV positron imaging applications. But for the PGCC imaging, the specific PG energy lines of interest are 4.44, 5.21, 6.13 MeV or even higher. Therefore, an absorber with LSO/LYSO crystal length longer than 20 mm should be more suitable. In this study, performance of absorbers using long crystals with single- and dual-ended readouts were measured and compared. Five 1.8×1.8 mm^2 LYSO arrays with lengths of 20, 30, 50, 80 and 100 mm were constructed. Each pixelated crystal was partially covered by enhanced specular reflector. To obtain the DOI responses, the long axis of crystal arrays were irradiated by collimated gamma rays from an F-18 radioactive source. The DOI positions with single-ended readout and dual-ended readout were determined using light-dispersion method and energy-dispersion method, respectively. The DOI resolutions of overall crystals with dual-ended readout were obtained from1.72 mm to 7.23 mm FWHM, and the energy resolutions were from 15% to 29 % FWHM. The results provide useful guidance in selecting the proper DOI absorbers, which can be used to build a PGCC to achieve both high spatial resolution and high detection efficiency performance.

Application of a SrI2(Eu) Scintillation Detector to In Situ Gamma-Ray Spectrometry in the Environment

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The importance of environmental radiation monitoring has increased after the occurrence of the nuclear accident at the Fukushima Daiichi nuclear power plant. In general, the high pressure ion chamber (HPIC) and GM counter are widely used as a radiation detector for monitoring the ambient dose rate in the environment as well as the nuclear facility. These detectors have a strength about the reliable and stable measurement of the ambient dose rate. However, they can only give the result of the measured ambient dose rate without the information of the artificial and natural radiation. The spectrometric determination of the dose rate using scintillation detectors is a very useful method with respect estimating the ambient dose rate as well as the nuclide contribution from measured energy spectrum, so that it is on an increasing trend using a NaI(Tl) scintillation detector in Korea. Because of its insufficient energy resolution to efficiently identify the released nuclides, such as 131I, 134Cs, and 137Cs, from the nuclear facilities, several spectrometers with a relatively good energy resolution has been attempting as an environmental radiation monitor. In this study, a SrI2(Eu) scintillation detector was used to perform the in situ gamma-ray spectrometry for the purpose of estimating the dose rate and radioactivity for detected gamma nuclides in the environment by applying the dose rate spectroscopy [1-3]. The Monte Carlo simulation of used SrI2(Eu) detector at 1 m above the ground was first conducted to calculate the detector response and its angular correction due to incident photons with a certain angle. After the preparation of the dose rate spectroscopy of the SrI2(Eu) detector used to simultaneously estimate the dose rate and radioactivity from the measured energy spectrum, in situ gamma-ray spectrometry using a SrI2(Eu) detector was conducted to determine the ambient dose rate as well as the individual dose rate and its radioactivity for detected gamma nuclides from only one measurement. The results were experimentally verified by an intercomparison of the in situ gamma-ray spectrometry results obtained by a portable HPGe semiconductor detector.

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Quantification of the movable neutron irradiator by using the europium-activated lithium iodide (^{6}LiI(Eu)) scintillator

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In recent years, the use of neutron area monitors has been increasing with neutron generators in airports and harbors in order to achieve the purpose of anti-terrorism and to search for unidentified materials in unopened state. Since the performance test of the neutron area monitors is only possible in the calibration facility of the primary or secondary standard institutes, it must be removed from the installation site and moved to the calibration facility to test. Such periodical detachments and movements can cause serious problem in the electrical and mechanical stability of the neutron monitor. In order to solve these problems, the need for the movable neutron irradiator and the radiological performance testing scheme has been raised.

In this study, the movable neutron irradiator was designed and fabricated considering mobility and radiological safety by using Monte Carlo N-Particle (MCNP) simulations, and the neutron fields constructed with the movable neutron irradiator were quantified by using an europium-activated lithium iodide [^{6}LiI(Eu)] scintillator in combination with the Bonner sphere spectrometer (BSS).

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Portable radiometric system for nuclear medicine

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Nuclear medicine requires variety of methods and equipment. The most popular device for nuclear diagnostic in Russia is an Anger camera. Shortcomings of those are the restricted field of view (typ. 50 × 50 cm) and the limited number of views available. Compact multi-detector medical radiometric system (MRS) was developed in Ural federal University to address the issue, while it can be used in assessments with Anger camera or without one to obtain more diagnostic information [1].

The purpose of this study is to describe the principles of constructing a software-hardware complex of the portable MRS for radionuclide assessments and to demonstrate its prospective clinical application.

The MRS consists of tiny body-attachable scintillation detectors. The main advantage of the system is the capability to perform scintigraphy assessments in several distant points of the body, while each detector could be positioned in an arbitrary point at arbitrary projection. One of the urgent applications of the MRS is the measuring the radiopharmaceuticals kinetics, while others are similar to most common radioisotope protocols, e.g. renal, liver, heart functional assessments. Specifically, those protocols have been well developed for the past decades and today are standardized for patients' regular monitoring in Europe and the US.

Portable radiometric system can make technical equipment of nuclear medicine laboratory more versatile. The device can be used for making simple examinations such as renal scintigraphy or for more complicated role such as an addition for Anger camera to evaluate hemodynamics of limbs in blood system examination.

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ZnAL2O4 powders and films for Ultra-Violet emitting phosphors

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Zinc Aluminate ($ZnAl_2O_4$) spinels are well known for their applications in optoelectronic devices, catalysis and chemical industry [1-3]. Recently $ZnAl_2O_4$ based phosphors have also been investigated due to their intrinsic UV luminescence for mercury free UV emission devices. [4, 5]

$ZnAl_2O_4$ powders were prepared by solid state reaction using ZnO and aAl_2O_3 as precursors. After mixing, grinding and pressing at 10 tonnes, the pellets were heat treated at 1200°C for 3 hours in air. $ZnAl_2O_4$ films were made using two different deposition methods: Spray-pyrolysis (SP) and pulsed laser deposition).The $ZnAl_2O_4$ obtained films and powders were analysed by XRD measurements. Radio-luminescence and cathodo-luminescence were also performed on both types of samples.

The $ZnAl_2O_4$powders prepared via solid State reaction, present a high intensity UV cathode and radio-luminescence around 250nm. The ratio between ZnO and aAl_2O_3 was tuned to optimize the luminescence intensity. Surprisingly, no or weak UV luminescence was detected in the case of films made by even though the required and pure phase was obtained. The UV luminescence in $ZnAl_2O_4$ is likely due to intrinsic defects into the material. However, the origin of these defects is not yet very clear. It has been reported that it might be due to oxygen vacancies [5]. In order to create these defects in the films, different synthesis parameters were modified such as the ZnO/aAl_2O_3 molar ratio and the post-deposition annealing temperature and atmosphere. Luminescence measurements obtained on the different films and the powders will be presented and compared.

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Microscopic and macroscopic defects propagation during inorganic oxides single crystal fibers grown from the melt

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Quite often during oxides fibers single crystal grown from the melt microscopic and macroscopic defects such bubbles [1-3] of average diameter higher than 100μm or micro-bubbles of diameter smaller than 10μm, color centers, dislocations, mosaic are observed. These defects strongly affect the crystal fibers properties and decrease the optical performances. The comprehension of the mechanism of bubbles creation and their mobility in the melting zone and in the vicinity of the crystallization interface are crucial to overcome their apparition and propagation. Bubbles of 100 μm diameter average are observed in the molten zone in garnet and sapphire single crystal fibers. Before their propagation inside the crystal they have a periodic oscillation, and consequently deform crystallization interface. Depending on pulling rate, seed orientations, thermal gradient defects such dislocations are generally observed and drastically decrease the optical properties and fibers performance. So the defects are a serious problem for the exploitation of the entire grown crystals and the pulled fibers. In this work, we show a direct visualization of bubbles defects in the molten zone, their movement in the liquid and their incorporation in fibers shaped crystal grown by the micro-pulling down technique. We will discuss results regarding the bubbles distribution as a function of seed orientation, thermal gradient and pulling rate.

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Positron Annihilation Lifetime Spectroscopy in Aluminum Garnets

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Positron annihilation lifetime spectroscopy (PALS) measurements in inorganic crystalline scintillator are performed using kapton enclosed ^{22}Na radioactive isotope as a positron source. Since there are only a few reports in literature concerning application of the PALS method for studies on wide band gap materials [1,2], especially on scintillators [3], we investigate materials with well-known trapping parameters to estimate the possibility of wider application of the method.

Room temperature positron lifetime measurements on a series of $\mathrm{Lu}_x\mathrm{Y}_{1-x}$AG:Pr crystals (where x = 0.00, 0.25, 0.50, 0.75, 1.00) using a fast-slow time coincidence setup are performed. Similar measurements are made on a different set of LuAG:Pr crystals, containing additionally some trace amounts of molybdenum at different concentrations. The lifetime spectra are deconvoluted and the resulting decay times are shown in relation to the trapping parameters obtained from thermoluminescence measurements [4].

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Development of luminescent transformers of solar light on the basis of the vanadate nanoparticles

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The RE-doped vanadate nanoparticles are intensively studied now in connection of their possible applications as luminescent down-shifting materials (LDS) from UV and violet spectral ranges into visible orange-red light. Such materials are needed for increasing of incident light harvesting by solar cells, obtaining of white light in powerful LEDs, medical applications, etc. Partial replacements of the RE cations with alkaline earth (AE) cations in the RE vanadate nanoparticles could cause increase of luminescent intensity and arising of additional excitation band near 400 nm [1-3]. Arising of excitation band around 400 nm is very desirable feature for the mentioned above practical applications of luminescent nanoparticles as the LDS materials.

In the present work, the basic REVO$_4$ compositions (RE = La, Eu, Sm) were doped with various concentrations of the AE modifying cations (AE = Ca, Ba, Sr) with the aim to shift absorption and luminescence excitation edges from 350 nm to 400 - 450 nm. The nanoparticles were prepared by aqueous nitrate-citrate sol-gel synthesis route using citric acid as a complexing agent. Phase compositions, crystal lattice parameters and average size of particles were determined using XRD procedure.

Complex spectroscopy study of reflectance, absorption and excitation spectra were carried out. Spectroscopy results were considered together with data of the XRD analysis as well as with data of both the SEM nanoparticles morphology and analysis of chemical element composition. The study revealed spectral bands caused by electronic transitions in various constituents of crystal lattice (VO$_4$molecular groups, own and dopants related defects). Processes those lead to formations of the LDS centers are considered.

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Manganese agglomeration and radiation damage in doped $Li_2B_4O_7$

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Nominally pure lithium tetraborate (LTB) is stable against radiation damage [1]. Doped LTB undergoes the radiation damage at lower radiation doses. LTB:Mn is used in radiation detectors (TLD-800). Despite a long history of investigations, it is actively studied till now [2, 3].

EPR and spectrally resolved thermoluminescence (TL) were studied for samples LTB:Me,Mn (Me = Mn, Sn, Cu, Be, Zn). The uniformity of Mn distribution strongly depends on synthesis procedure and co-dopants added: Sn and Cu decrease Mn agglomeration, while Be and Zn increase that. The balance between electron and hole traps is crucial. The unbalanced electron traps make holes trapped at B-O-B bonds between BO_4 and BO_3. This way created defects are stable up to 620-640 K, disappear at higher temperatures, and some fraction of them turns into the other unknown paramagnetic defects. All radiation defects are cleaned by annealing under flowing argon at about 900 K. The samples with agglomerated Mn (e.g. LTB:Be,Mn) undergo the higher radiation damage. When Mn is agglomerated, the TL maximum at 480-500 K in LTB:Mn shifts towards higher temperatures at high radiation doses. At lower doses, the TL maximum returns back. Sometimes, the irreversible changes are observed in TL curve due to Mn migration during heating and cooling cycles. Multiple cycles slightly decrease the amount of hole traps thus increasing the possibility of radiation damage.

The LTB:Sn,Mn is most stable against high radiation doses, having slightly lower sensitivity against bare LTB:Mn.

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Iono- and photoluminescence characterization of radiation damage in dielectric crystals induced by swift heavy ion irradiation

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In this report we summarize results of high energy ionoluminescence experiments aimed at comparative studies of radiation defects and associated stresses in LiF, Al_2O_3 and MgO single crystals. These materials demonstrate different sensitivity to dense ionization effects. As known, swift heavy ions induce formation of latent tracks in alumina oxide and lithium fluoride [1], while no tracks as well as no amorphization have been observed in magnesium oxide even at very high ion fluences [2].

Dose dependence of the ionoluminescence spectra measured from Al_2O_3 during 1.2- 1.6 MeV Kr and Xe ion irradiation clear evidences different stages in damage and stress accumulation at fluences before and after ion track overlapping. Contrary, real-time examination of MgO at the same experimental conditions did not reveal the changes in the ionoluminescence spectra which could be ascribed to mechanical stresses in the irradiating crystals.

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Luminescent properties of Eu^{2+}/Eu^{3+} in $NaCaPO_4$ matrix containing SiIP defects

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A series of materials based on a sodium calcium phosphate matrix doped with europium and different concentrations of silicon ions were synthesized using the Pechini method. The method is based on a mixing of positive ions in a solution, controlled transformation of the solution into a polymer gel, removal of the polymer matrix and calcination of an oxide precursor with a high degree of homogeneity [1,2]. A two-step strategy of synthesis was applied. This strategy involved an initial annealing of mixture of reagents under atmosphere of air and then, after cooling and grinding the product, the reduction-under hydrogen/nitrogen atmosphere. The phase composition analysis as well as spectroscopic measurements were performed to characterize the obtained phosphors. The XRD patterns show that in all cases the obtained materials consist of pure phase of $NaCaPO_4$. Emission spectra of materials obtained after first step of the synthesis consist of narrow bands, which are characteristic for $^5D_0 \rightarrow ^7F_J$ transitions in Eu^{3+} ion. However for the materials co-doped with silicon ions the additional Eu^{3+} site is observed which is not observed for materials doped only with europium. The emission spectra of materials, which were obtained after reduction process, are characterized by the intensive, broad band attributed to the d-f transitions in Eu^{2+} and narrow bands at 619 nm attribute for the europium 3+ ion (the incorporation of silicon ions causes the stabilization of the Eu^{3+} ions under reductive atmosphere). The observed differences in europium luminescence are discussed taking into account creation of different compensation defects.

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Influence of point defects on the electronic structure and luminescence properties of Li_2MoO_4 crystals

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Several molybdate crystals, including Li_2MoO_4 have been recognized recently as perspective working materials for cryogenic scintillation bolometers [1]. Understanding of the luminescence mechanisms in Li_2MoO_4 is of high importance since it can help to grow samples with satisfactory scintillation characteristics. The present work reports the results of the electronic band structure calculations and experimental studies of the optical and luminescence properties of $Li_2MoO_4$with various concentration of point defects.

The lithium molybdate charge was obtained by a solid-state synthesis technique from MoO_3 (99.5 % or 99.9 % purity) and Li_2CO_3 (99.5 % or 99.99 % purity) powders. Single crystals of Li_2MoO_4were grown by the Czochralski technique in a Pt crucible in room atmosphere or dry air. The luminescence characteristics under photo- and X-ray excitations, the IR and optical transmission spectra, TSL characteristics of the grown Li_2MoO_4 samples were measured and analyzed.

The geometry optimized calculations of the electronic band structures and optical constants of ideal and defect-containing Li_2MoO_4 crystals were performed in a supercell approach using the FP-LAPW method [2]. The 2x2x1 supercells were chosen for calculations of various kinds of defects: cation $V_{Li}$and anion vacancies V_O, substitutional $M^{II}{}_{Li}$ (M^{II} = Ca, Sr, Zn, Cd) and interstitial (Zn_i, $(MoO_3)_i$) impurities, and also several combinations of point defects. The partial densities of states, the linear optical properties (including absorbance and reflectance spectra) and defect transition levels (defect ionization energies) were calculated and analyzed.

The influence of studied point defects on the luminescence processes in Li_2MoO_4 crystals was discussed on the ground of obtained experimental and calculation results.

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Impurity type defects in crystalline cubic boron nitride. A correlated ESR, SEM and CL study on cBN crystals

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Crystalline boron nitride, with cubic zinc blende structure (cBN), is a synthetic wide band-gap (6.25eV) semiconductor, produced in submilimeter sizes by high pressure-high temperature (HP-HT) synthesis [1]. With thermo-mechanical properties comparable or even superior to diamond, it can be relatively easily *p*- and *n*-doped resulting in *p-n* junctions and UV LED's operating at T=900K, without significant changes in their electrical and optical parameters [1,2]. Developing this material for various applications including radiation detection, requires a much better knowledge on the nature and distribution of the intrinsic and radiation induced defects. Previous investigations by Electron Spin Resonance (ESR) [3], photoluminescence (PL) and cathodoluminscence (CL) [4,5] resulted in the observation of a large variety of defects. The absence of any clear hyperfine structure of in the ESR spectra of the reported paramagnetic defects suggested the presence of impurities aggregation processes. Consequently, in an effort to get a better insight into the presence, nature and distribution of the impurities in cBN crystals we performed ESR, scanning electron microscopy (SEM) and cathodoluminscence (CL) measurements on such amber colored plate-like single crystals of 200 microns the largest size from a batch of the largest grained super abrasive powder from the same producer. The results of the investigations confirm the non-uniform distribution of impurities from the starting materials, supporting their suggested aggregation tendency. The nature of the most likely impurities involved in formation of the paramagnetic centers is also discussed.

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Defect reduction and europium ion luminescence enhancement in hafnia nanocrystals

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In this work, the optical properties of HfO_2:$Eu^{3+}$and HfO_2:Eu^{3+}, Nb^{5+}, synthesized using the sol-gel method and annealed at various temperatures are studied. The goal of this study was to confirm that similar to previous studies of zirconia, Nb^{5+}in HfO_2:Eu,Nb acts as a charge compensator and enhances Eu^{3+}ion luminescence intensity (in this study for up to 15 times) by reducing the amount of defects present. The reduced amount of defects in undoped hafnia and hafnia doped with Eu5%, Eu5% and Nb5%, was confirmed via thermostimulated luminescence studies. Furthermore the photoluminescence spectra of the sample conataining Nb also showed a reduced intensity for the 607nm line, which is associated with oxygen vacancies, again confirming that the amount of defects has lessened. It is concluded that the resulting photoluminescence is mainly affected by oxygen vacancies in the crystal lattice and their relocation due to phase change or annealing temperatures rather than changes in the local crystal field itself.

Electron trapping centers in $Y_3Al_5O_{12}$ and $Lu_3Al_5O_{12}$ crystals

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$Y_3Al_5O_{12}$ (YAG) and $Lu_3Al_5O_{12}$ (LuAG) are widely exploited as luminescent and scintillation materials in the high-tech industry, medicine and security imaging and monitoring systems, and in the solid state white light sources. In spite of the favorable scintillation properties, their main demerit is the presence of slow components in the scintillation decay due to presence of host defects. Among different possible defects, so-called antisite ion defects and oxygen vacancies are the most frequently mentioned intrinsic defects in garnet crystals. Oxygen vacancy (V_O) serves as an effective trap for electrons. It can be thus filled by one or two electrons creating F^+ and F^0 centers. In spite that F centers usually produce absorption band in the visible or UV region, identification of these centers by only optical methods is quite questionable. In this respect, the F^+ centers, being paramagnetic, can be successfully identified and studied by electron paramagnetic resonance (EPR).

In this report we present results of detailed EPR investigation of YAG crystals with strong up to 0.1-0.2 at.% concentration of F^+ centers. The measurements were performed using the Bruker E580 spectrometer. In addition, to resolve hyperfine interaction of trapped electron, Electron Nuclear Double Resonance (ENDOR) technique was utilized as well. The crystals were grown by the Czochralski method in pure reducing atmosphere. They were colored from light to deep blue color. These crystals show quite strong EPR signal even at room temperature at the g factor 1.99. The spectrum intensity decreases with temperature decrease due to saturation effects. So that it could not be measured below 100 K. At T<100 K the “true” undistorted spectrum was obtained by pulse technique using the spin-echo detection of EPR. At the temperature 20 K, the spectral line becomes slightly anisotropic due to anisotropy of g factor. ENDOR spectra clearly resolved hyperfine interaction of trapped electron with nuclear spins of surrounding Al ions. Besides of the two closest ^{27}Al nuclei in the vicinity of V_O, we have resolved the next-nearest-neighbor four ^{27}Al nuclei which contribute to the hyperfine interaction indicating that the wave function of trapped electron spreads far over V_O volume. The F^+ center EPR signal disappears after annealing of the colored crystal in air atmosphere. The crystal becomes completely transparent as well. All these observations are characteristic features of F^+ center, i.e. electron trapped at oxygen vacancy. Similar center, related to oxygen vacancy, was also identified in LuAG crystals.

Visible and IR luminescence of complex centers at 4-300 K, created by thermo-optical treatment in anion-deficient corundum

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The possibility of the F_2 - and Al_i - type complex aggregates non-radiation creation in anion-deficient corundum (α-Al_2O_{3-d}) crystals by means of special thermo-optical treatment (TOT) was demonstrated in [1].

Comparative systematic studies of the luminescent and spectral absorption complex centers properties created by TOT and electron irradiation in α-Al_2O_{3-d} and neutron irradiation in nominally pure corundum crystals of stoichiometric composition (α-Al_2O_3) were carried out. It has been established that the F_2 - and Al_i - type centers which are created by TOT and electrons and neutrons irradiation and get excited and emit in the UV and visible regions of the spectrum, have the same spectral optical properties. Thus, they associate with absorption bands at 4.07, 3.47, 3.24 and 2.76 eV and with emission bands, respectively, at 3.82, 3.29, 3.15 and 2.64 eV. At low temperatures, a well-known fine structure with zero-phonon lines (ZPL) and phonon replicas is observed in these bands, which is the same as in [2].

It is unusual for TOT-created centers that some of them have radiative transitions in the IR region. At helium temperatures, the IR luminescence bands are highly structured. Part of the detected infrared radiative transitions in thermooptically treated α-Al_2O_{3-d} crystals coincide with those in the neutron-irradiated α-Al_2O_3 samples, particularly transitions with peaks at 1.41 and 1.25 eV, and the ZPL at 1.640 and 1.355 eV respectively [3]. Furthermore, thermooptically treated α-Al_2O_{3-d} crystals has IR transition with a maximum at 1.0 and ZPL at 1.155 eV, which did not show up in the neutron-irradiated α-Al_2O_3crystals. Based on the known facts about the absorption and emission transitions displacements to lower energy regions with the increase of *n* in aggregate F_n -type centers and the electron-phonon interaction forces lowering, manifesting in the occurrence of more advanced fine structure of the luminescence bands, it can be stated that by using reductive heat treatment and TOT, as well as the variation of their regimes, defects can be created in a wide variety of corundum crystals, ranging from simple F^+ - and F - type to the aggregate F_n - centers with $n \geq 2$.

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Thermally stimulated processes in the luminescence of carbon-oxygen complexes in h-BN micropowder

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The goal of the present work is to study thermally stimulated luminescence (TSL) and photoluminescence (PL) thermal quenching processes in 3.75-eV band under band-to-band excitation of h-BN samples characterized with high concentration of carbon and oxygen impurities. The studied hexagonal boron nitride micropowder was synthesized by the modified O'Connor technique. Attestation of the samples showed that powder demonstrated flake-like morphology with average particle size of 7±3 μm and graphitization index g = 1.7-2.5. Atoms of C (2.9 at.%) and O (0.6 at.%) are the main impurities in the samples. TSL curves and PL thermal quenching dependencies were measured in the 330±10 nm (3.75 eV) band within the 300-773 K range using the installation based on the Perkin Elmer LS55 fluorescence spectrometer with the integrated high-temperature accessory. The studied h-BN micropowder was irradiated at room temperature with the 210±5 nm (5.9 eV) phonons during 5 min prior to the TSL measurements. The same photon energy was used for PL excitation in the samples.

It was shown that TSL response within the 3.75 eV band characterized by low- (P1) and high-temperature (P2) peaks with temperature maxima at T_{max} = 340 and 610 K, correspondingly. Moreover, P1 peak had 3.3 times higher intensity and 1.7 bigger area in comparison to P2 peak. Estimates of the kinetic parameters values for the studied TL peaks were performed using Peak Shape, Curve Fitting and Initial Rise methods. Activation energy values were found in E_a = 0.7-1.0 and 1.5-2.0 eV range and frequency factor - in $S = (1\text{-}5)\times10^{14}$ and $(5\text{-}10)\times10^{10}$ s^{-1} for peaks P1 and P2 respectively. It was obtained, that the thermally activated processes of general (b = 1.3) and first (b = 1.0) kinetics order dominated for peak P1 and P2, respectively, within the considered temperature range in h-BN under UV excitation.

During the PL thermal quenching analysis it was found that the intensity of PL increased with the growth of the temperature up to 400 K, stabilized in T = 400-500 K range, then decreased with $T \geq 500$ K and finally lowered down to the background values at T = 700 K. Quantitative approximation of the measured PL thermal quenching dependencies was performed, values of corresponding microparameters were calculated.

It was assumed that luminescence in 3.75 eV band can be caused by the carbon-oxygen impurity complex. Therefore P1 and P2 TSL peaks had electron origin and were due to 1B- and 3B-centers, respectively. Allowing for the obtained experimental data as well as the independent results the band diagram for mechanisms of thermally stimulated processes with the participation of the impurity defects in the h-BN under UV-irradiation was modified.

The Luminescence of Diamonds

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This work presents luminescence characteristics of undoped diamonds deposited on silicon and quartz substrate using HF CVD. Using luminescence technique as CL (Cathodoluminescence), TL (Thermally stimulated luminescence), PL (Photoluminescence) will be shown informations conected with optically active defects (color centers). The relationships, which exist between the luminescence of diamond and its conditions of deposition process, will be visible in the nature of the results.

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Structure of defects in semiconductor cubic crystalline boron nitride. A microstructural and microanalytical investigation.

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As a wide band-gap (6.25eV) semiconductor, superhard crystalline boron nitride (cBN) exhibits electrical, optical and thermo-mechanical properties comparable or even superior to diamond [1]. Developing this material for various applications, including radiation detection, requires enlarging the actual limited knowledge concerning the presence and nature of the impurity and lattice defects in the available submilimeter sizes cBN crystallites prepared by high pressure-high temperature (HP-HT) synthesis. Previous investigations by Electron Spin Resonance (ESR) [2] and luminescence [3,4] resulted in the observation of a large variety of defects. The absence of any hyperfine structure in the ESR spectra suggested the presence of impurity atoms with zero nuclear moment in their structure and/or aggregation processes [2]. Consequently, we decided to investigate the presence and distribution of impurities and lattice defects in amber and dark colored cBN crystallites of up to 200 microns, the largest size commercially available as super abrasive powders. The investigations were performed by analytical high resolution scanning/transmission electron microscopy (analytical-HRTEM/STEM), scanning electron microscopy (SEM) and electron dispersive X-ray analysis (EDX). Our microstructural investigations revealed the presence of extended defects: microtwins, dislocations and precipitates. Meanwhile the analytical techniques underlined the presence of oxygen as one of the main incorporated impurity. Annealing experiments performed in vacuum ($< 10^{-4}$mbar) at 900 ^{0}C resulted in the formation, in the cooler parts of the pure quartz tube holding the investigated cBN samples, of a crystalline deposit containing SnO_2.

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Role of electron and hole centers in energy transfer in SrBrI and BaBrI crystals

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Crystals of alkaline earth halides BaBrI and SrBrI doped with Eu^{2+} ions are promising scintillators with a high light output [1-3]. Some of their scintillation properties have been detailed studied [1, 2], however the radiation resistance of these crystals, as well as the formation of radiation defects in them, have not been studied.

In this paper we study electron and hole centers in irradiated SrBrI and BaBrI crystals using optical spectroscopy and ab initio methods. Optical absorption spectra, thermostimulated (TSL) and photostimulated (PSL) luminescence in wide temperature range 7-300 K are studied.

It is found that absorption bands in VUV or X-ray irradiated crystals appeared in the region of 1.6 and 1.85 eV are attributed to F-centers. The efficiency of the creation of these centers is substantially reduced at temperatures below 80 K, in the region where the intensity of the emission of excitons increases [3]. Optical absorption spectra of F-centers and position of ground state of F-centers in band gap are calculated. The calculated results agree well with the experimental ones.

Doping with europium or oxygen ions increases the radiation resistance of the crystals. Stimulation in the red region of the spectrum exhibits intense photostimulated luminescence in the crystals irradiated at liquid nitrogen temperature. The excitation spectra of PSL are found in region of the absorption band of the F centers. In the paper mechanism of radiation defect creation and role of F-centers, hole centers and excitons in energy transfer will be discussed.

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Optical study of divalent rare-earth ions absorption in x-irradiated alkaline earth fluorides crystals

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Studying the effect different states have on valence stability of impurity ions, or on the change in their valence under an external impact, is of both practical and fundamental interest.In this work we present the results of the research the absorption spectra of radiation-colored CaF_2, SrF_2, and BaF_2 crystals activated by trivalent Pr, Sm, Ho, Er, Tm, and Yb (RE) ions.

The CaF_2, SrF_2 and BaF_2 crystals doped with REF_3 (from 0.1 to few mol. percent) have been grown from the melt by the Stockbarger method in graphite crucibles in vacuum. At the first stage, pure crystals were grown with addition of some amount of CdF_2 to the raw material in order to remove oxygen. Then crystals with an impurity of rare earth fluorides (MeF_3) were grown from the crystalline raw material. The absence of oxygen in the final crystals was controlled by the absence of oxygen luminescence under sample illumination by DDS-30 UV deuterium discharge lamp. The crystals CaF_2, SrF_2, BaF_2 were irradiated at 80 K or 300 K by X-rays from Pd tube operating at 35 kV and 20 mA for not more than 1 h. The thermal decay of the radiation defects in temperature range 80-700 K was studied. The optical absorption spectra were measured at 80 and 300 K with a Perkin-Elmer Lambda 950 UV/VIS/NIR spectrophotometer at the Isotope-geochemical research center for Collective Use, Siberian Branch, Russian Academy of Sciences.

It is shown that the radiation coloring of CaF_2, SrF_2, and BaF_2 crystals activated by trivalent Pr, Sm, Ho, Er, Tm, and Yb ions results in the formation of divalent impurity ions, along with hole $F_3{}^-$ and $(F_2{}^-)_{ii}$ centers. The divalent Sm ions in crystals are the ones most thermally resistant. The temperature resistance of the divalent RE ions in radiation-colored CaF_2 crystals correlates with the chemical stability of compounds with divalent RE ions.

Spectroscopic characterization of soft X-ray irradiated lithium fluoride thin films thermally evaporated from pure and doped powders

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Luminescence properties of point defects in insulating materials are successfully used for solid state light sources and radiation detectors. Among them, radiation-induced colour centres in lithium fluoride, LiF, are well known for their application in optically pumped tuneable lasers, miniaturized photonic devices, dosimeters and novel radiation imaging detectors [1]. LiF film detectors, based on the exploitation of the peculiar photoluminescence characteristics of F_2 and $F_3{}^+$ defects, were successfully tested for extreme ultraviolet radiation, soft and hard X-ray using pure LiF powder as starting material [2]. In this work, LiF films were grown by thermal evaporation on amorphous substrates (glass and silica) starting from LiF:Mg,Cu,P powder (Radcard, Poland), containing Mg, Cu, P impurities, and commonly used for thermoluminescence dosimetry [3]. They were irradiated simultaneously with LiF thin films grown from pure LiF powder (Merck Suprapur, 99.99% pure) by soft X-rays emitted by a point-like Nd-YAG pumped laser plasma source, equipped with a Cu target. Under blue laser pumping at 445 nm, in the overlapping absorption bands of broad-band light-emitting F_2 and $F_3{}^+$ electronic defects, stable at room temperature, the photoluminescence spectra span over the green-red visible spectral range. First preliminary results shows intensity and spectral differences, which highlight the critical role of material purity in the active colour centres formation and emission characteristics.

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Afterglow luminescence in Eu2+ and Mn2+ doped NaScSi2O6 clinopyroxenes

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Clinopyroxenes of general chemical formula $NaMe^{3+}Si_2O_6$ are members of big family of pyroxenes compounds, which are interesting as functional materials. Recent publications [1, 2, 3] show that upon doping with Eu and Eu/Mn they exhibit interesting properties for application as phosphors for white-light-emitting diodes. $NaScSi_2O_6$ clinopyroxenes (jervisite) doped with Eu^{2+}(5%)/Mn^{2+}(15%), prepared by sol-gel method, exhibit afterglow fluorescence in red region of the spectrum, associated with Mn^{2+} emission. This afterglow luminescence is excited by the UV light, including excitation above the band-gap of this material, located around 4 eV. This emission may be interesting also for biological application in the first biological window and as thermoluminescence detector of radiation dose emitting in the red region.

Materials doped only with Mn^{2+} in addition to typical band related to $^4T_1$ –> $^6A_1$ Mn^{2+} intrashell transitions with a maximum around 660 nm exhibit also an additional intense broad band luminescence in the infrared region with a maximum at 850 nm, that decay exponentially with a decay time equal to 24 μs at room temperature. The defect, to which this band is related may be also responsible for relatively low quantum efficiency (only about 20%) of this phosphor doubly doped with Eu^{2+} and Mn^{2+}, Non-exponential character of Mn^{2+} decay kinetics in the studied samples support this conclusion. Additional studies of this defect are presented.

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Photochemical synthesis and characterization of multi-component garnet powders

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Synthetic garnet materials doped with lanthanide ions, based on the cubic structure of pyrope $Mg_3Al_2(SiO_4)_3$ with rare-earth elements on the Mg site, have been receiving significant attention for several decades in the field of solid-state lighting, lasers or scintillator detectors. Their versatility in the composition and the possibility to tune their luminescent properties to mitigate some inherent defects have been intensively studied, especially in the $(Gd,Lu)_3(Ga,Al)_5O_{12}$ composition [1]. In addition to the most common single crystalline form, nano-crystalline garnet materials with many potential applications can be prepared as well, e.g. by a co-precipitation (Pechini) or radiation-induced methods. The latter technique features an irradiation of aqueous solution with UV light or ionizing radiation to induce chemical reactions leading to the formation of nanometre-sized particles, which crystallize into garnet nanoparticles after a proper calcination procedure [2]. This method also allows to prepare highly complex materials either with multiple metal ions, or possibly with different layers.

In this work, radiation-induced method followed by calcination at high temperatures (1000 - 1500 °C) was used to prepare nano-crystalline garnet powders of $(Gd,Lu)_3(Ga,Al)_5O_{12}$ garnet doped with Ce and several core-shell materials featuring a $Gd_3(Ga,Al)_5O_{12}$ core and gold, thick silica, or $Lu_3Al_5O_{12}$-based shell. The structural and elemental composition was determined using X-ray diffraction and X-ray fluorescence, and their luminescent properties were evaluated under X-ray excitation. For high concentration of Ga ions used, the temperature needed to obtain a pure garnet phase increases along with the mean crystallite size and the Ce^{3+} 5d-4f emission band shifts with changes in both Gd and Ga content. The structural and luminescence properties of the prepared powders will be presented and discussed with particular attention to the influence of composition and calcination temperature. The potential of the radiation-induced method with respect to core-shell structures will be also evaluated.

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Ab initio Molecular Dynamics Study of Diffusion Mechanism of Self-trapped Holes in BaF2 and LaF3 Crystals

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Ab initio molecular dynamics (MD) is one of the most efficient methods to study electronic excitations and point defects in ionic crystals, including Vk-centres. MD is capable of finding defect equilibrium configurations and plotting time and temperature dependencies of defect diffusion probabilities.

In the present work this method was applied to study the Vk-centers in BaF2 and LaF3 crystals. We used the density functional theory in the DFT+U approximation at PBEsol level with U=11 and J=3 values for 2p-orbitals of fluorine to provide a qualitatively correct description of the hole localization. The distance between the fluorine ions forming the self-trapped hole is about 1.9 - 2 E in all crystals. The MD simulation was performed for temperature linearly increasing from 70 to 600 K. In BaF2 crystal three possible diffusion channels of Vk-center were observed: (i) jump along the defect axis, (ii) 90° reorientation, and (iii) jump through an intermediate state. The intermediate state appears when one of the fluorine ions composing Vk-center is displaced into the nearest interstitial position and may be considered as the pair of nearest anion vacancy and H-center. This intermediate state is unstable and disintegrates shortly either by returning to an initial Vk-center configuration or by the bond switching with subsequent Vk-center reorientation.

In LaF3 crystal with tysonite structure there are three different anion sublattices: F1 sublattice consists of fluorine layers between the lanthanum planes, while the fluorine ions positioned is the lanthanum planes form F2 and F3 sublattices. In the latter (F3) they are slightly shifted along the crystal c-axis. From the results of molecular dynamics we have established four possible configurations of self trapped hole in LaF3 crystal: 1) between fluorine ions in the same layer of F1 anion sublattice; 2) between F1 and F3 sublattices; 3) between F1 and F2 sublattice; 4) between fluorine ions from nearest parallel layers of F1 sublattice. The configuration 4 is the most energetically favorable, while the configurations 1-3 have the total energies higher.

Development of single crystalline film scintillators based on the of Tb^{3+} doped $Lu_{1-x}Gd_xAlO_3$ mixed perovskites

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Single Crystal Film (SCF) scintillators are key-components of today's high-resolution 2D X-ray detectors used at synchrotrons for applications in X-ray microtopography. Due to its high density and effective atomic number, the rare-doped mixed $Lu_{1-x}Gd_xAlO_3$perovskites has a great potential to replace or complement the currently used Eu^{3+} doped $Gd_3Ga_5O_{12}$ garnet and Tb^{3+} doped Lu_2SiO_5 orthosilicate SCF screens. The X ray absorption edge of these mixed perovskites can be significantly improved in the 50-60 keV range due to the characteristic absorption of Gd^{3+} and Lu^{3+} cations.

In this report we present the systematic results on the growth and investigation of the luminescent and scintillation properties of the solid-solution of Tb^{3+} doped $Lu_{1-x}Gd_xAP$ SCF at x=0-1, grown onto undoped $YAlO_3$ substrates by the Liquid Phase Epitaxy method. The structural properties of the SCFs were characterized using X-ray diffraction and electron scanning microscopy. We have found that the best structural properties are observed for $Gd_{0.5-0.55}Lu_{0.5-0.45}AP$:Tb SCFs, where the SCF/substrate misfit is close to zero.

For characterization of the luminescent properties of Tb^{3+} doped $Lu_{1-x}Gd_xAP$ SCF, the absorption, cathodo- (CL), photo- (PL) and X-ray excited luminescence (RL) measurements were used. The light yield (LY) of $Lu_{1-x}Gd_xAP$:Tb SCF, depending on x value in the 0-1 range, was measured under e-beam, α-particles and X-ray excitation. For investigations of $Gd^{3+} \rightarrow Tb^{3+}$ energy transfer in the perovskite hosts, the luminescent spectroscopy of Tb^{3+} doped GdAP and LuAP SCFs under excitation by synchrotron radiation was applied as well.

We have shown that the Tb-doped $Lu_{1-x}Gd_xAP$:Tb SCFs are very efficient X-ray scintillators. The $Gd^{3+} \rightarrow Tb^{3+}$ energy transfer is observed in $Lu_{1-x}Gd_xAP$:Tb SCF, giving reasons to increasing the efficiency of the Tb^{3+} luminescence in the perovskite hosts. The highest LY of the CL and RL under excitation by e-beam and α-particles is found in $Gd_{0.5}Lu_{0.5}AlO_3$:Tb SCF. The LY of CL and RL of these SCF is notably higher than that in the conventional $Gd_3Ga_5O_{12}$:Eu SCF screen using now in the microimaging detectors. Recently, we have demonstrate the efficient Ce →Tb energy transfer in LuAP:Tb,Ce SCF. Therefore, the LY of $Lu_{1-x}Gd_xAP$:Tb SCFs can be additionally increased by co-doping with Ce^{3+} ions.

Finally, Tb^{3+} and Tb^{3+}-Ce^{3+} doped $Lu_{1-x}Gd_xAP$ SCF samples were evaluated for X-ray microimaging using a spatial resolution targets at the ESRF, France and DESY, Germany.

Influence of growth parameters on scintillation properties of InGaN/GaN heterostructures

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Nowadays, nitride semiconductors can be found in many optoelectronic (light emitting diodes) and electronic (high electron mobility transistors) devices. Another important field of applications is in scintillation detectors. There is an enormous demand for high-luminosity scintillators with fast decay to further improve the time-of-flight based detectors or using them in synchrotrons or other accelerators for beam diagnostics. Fast scintillators are necessary in scanning electron microscopes for industrial inspection of today's electronics. Gallium nitride has very promising scintillation properties due to its strong exciton binding energy, high radiation resistance and temperature stability. GaN epitaxial layers grown by Metal-Organic Vapor Phase Epitaxy (MOVPE) for application in scintillation detectors [1] were studied. These layers had decay time below 1 nanosecond but suffered from a quite low external photon yield. On the other hand, if we grow heterostructures based on InGaN quantum wells and GaN barriers, we can increase the photon yield of these structures thanks to the quantum confinement in these 2-D multiple quantum well structures.

In our research, we grow InGaN/GaN heterostructures by the MOVPE technology and study their scintillation properties by different characterization methods [2,3]. In this work, we will discuss how different growth parameters and modifications of the structure (growth temperature of quantum wells, thickness of the cap layer, Si doping of layers, thickness and composition of quantum wells, etc.) influence scintillation properties. Photoluminescence (PL) and cathodoluminescence (CL) measurements were used for characterization of our structures. Decay time was studied with time-resolved radioluminescence. Other results obtained from excitation-emission PL maps or band structure simulations (by software NextNano) will be discussed.

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Effect of Sintering Temperature on the Microstructure and Luminescence of LuAG:Pr Ceramics

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In the mid-2000's, $Lu_3Al_5O_{12}$:Pr (LuAG:Pr) ceramic scintillators were introduced as candidates for the next generation of positron emission tomography (PET) scanners. However, there remains a knowledge gap relating the fabrication and processing conditions of ceramic scintillators with their luminescent properties, a situation that negatively impacts a broader use of these materials. For example, open-volume defects generate light scattering and degrade optical performance, while electronic traps capture charge carriers and decrease the yield of radiative recombination at the luminescence center. The fabrication of ceramics involves numerous processing steps, in particular high temperature sintering, each of which impacting optical and scintillation performance. In this work, the effects of sintering temperature from 1400 to 1700 ^{o}C for 20 hrs in air on the microstructure and luminescence properties of LuAG:Pr ceramics were investigated using a single crystal as reference. The density was determined by means of the Archimedes' method to increase for higher temperatures, reaching a maximum value of 93% of the theoretical density, concomitant with the increase of the average grain size from 0.4 to 2 mm as determined by scanning electron microscopy (SEM) imaging. The microstructure was characterized by X-ray diffraction (XRD) and attenuated total reflection Fourier transform infrared (ATR FTIR) spectroscopy. These results showed narrowing of diffraction peaks, an increase of the lattice parameter, and the elimination of an amorphous phase present even after sintering at 1500 ^{o}C for higher sintering temperatures, together with changes in the ATR FTIR spectra that reflected a progressive structural evolution toward a more organized polycrystalline structure. Photoluminescence (PL, PLE), and radioluminescence (RL) measurements obtained under X-ray excitation revealed the presence of the 5*d*->4*f*, 4*f*->4*f* and defect emissions. The integral contribution of the 5*d*->4*f* transitions increased at the expense of the 4*f*->4*f* transitions for higher temperatures. Moreover, Gaussian spectral deconvolution analysis of RL results revealed the variation of the relative contribution of the several transitions that compose the broad 5*d*->4*f* emission (final states $^3F_{3(4)}$, $^3H_6$, $^3H_5$ and $^3H_4$). Thermoluminescence measurements at 1 ^{o}C/s showed intense glow peak at 225 ^{o}C for the ceramics, 20 ^{o}C lower than the position for the main glow peak detected for the single crystal. The single crystal also presented weaker glow peaks at 165 and 285 ^{o}C that were not present for the ceramics. In addition, all samples presented a weak glow peak around 93 ^{o}C and TL signal above 330 ^{o}C. Overall, there was a strong decrease in the integral TL signal toward saturation for sintering temperatures above 1400 °C.

Enhancement of the Eu^{3+} luminescence in the Eu-Ag co-doped $Li_2B_4O_7$ glasses

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The luminescence properties of the Eu-doped and Eu-Ag co-doped glasses with $Li_2B_4O_7$ (Li_2O-$2B_2O_3$) basic composition are studied using optical absorption, photoluminescence (excitation, emission, decay kinetics), and quantum yield (QY) measurements. The $Li_2B_4O_7$:Eu and $Li_2B_4O_7$:Eu,Ag glasses were obtained in the air using standard glass technology, briefly described in [1]. The XRD patterns of obtained materials confirm their disordered glassy structure. The optical absorption spectrum of the Eu-doped borate glass consist of several narrow bands, which belong to characteristic *f*-*f* transitions of Eu^{3+} ions. Absorption spectrum of the annealed $Li_2B_4O_7$:Eu,Ag glass additionally shows a broad band in the range of 400 - 430 nm attributed to the surface plasmon resonance absorption of silver nanoparticles.

The photoluminescence spectra of the $Li_2B_4O_7$:Eu and $Li_2B_4O_7$:Eu,Ag glasses registered under excitation with λ_{exc} = 393 nm ($^7F_0$ - $^5L_6$ transition) are closely similar and reveal intense emission bands in the 570 - 710 nm spectral range, which correspond to the $^5D_0$ - ^7F_J (J = 0 - 4) transitions of Eu^{3+} ions. Luminescence kinetics of the Eu^{3+} centres is satisfactory described by single exponential decay with lifetimes in the 2.18 - 2.23 ms range. The Ag impurity in the $Li_2B_4O_7$:Eu,Ag glasses shows broad emission band with a maximum about 415 nm that can be efficiently excited by photons in the range of 350 - 360 nm. The observed luminescence was ascribed to small molecule-like non-plasmonic silver nanoclusters or nanoparticles [2].

The enhancement of Eu^{3+} luminescence in the $Li_2B_4O_7$:Eu,Ag glass have been observed. The external QY of Eu^{3+} luminescence increases in 2.5 times in the $Li_2B_4O_7$:Eu,Ag glass in comparison with $Li_2B_4O_7$:Eu glass. Such enhancement is attributed to the energy transfer from very small molecule-like non-plasmonic silver aggregates to the Eu^{3+} ions as the major factor and local field effects induced by surface plasmon resonance of the silver nanoparticles. The obtained external QY of the Eu-Ag co-doped $Li_2B_4O_7$ glass are higher than the QY of other Eu-doped oxide glasses and comparable with the QY of well-known Y_2O_3:Eu commercial phosphor. Based on the obtained results one can to conclude that the $Li_2B_4O_7$:Eu,Ag glass are promising luminescent materials in the red spectral range.

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Luminescence and scintillation performance of ternary cesium hafnium chloride single crystals grown by vertical Bridgman method

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Halide materials have been intensively studied as promising scintillators due their high light yield and excellent energy resolution, however, their hygroscopic nature limits their application potential. On the contrary, ternary cesium hafnium chloride (Cs_2HfCl_6) with its low hygroscopicity, high atomic number Z = 58, high light yield up to 54 000 ph/MeV, energy resolution of 3.3% at 662 keV, scintillation response of 4.4 μs (95 % of energy) at 662 keV, and moderate density of 3.86 g/cm^3 fulfills requirements as a suitable candidate for radiation detector [1]. The Cs_2HfCl_6 belongs into family of compounds isostructional to K_2PtCl_6 crystallizing in cubic crystallographic structure with lattice parameters a = 10.42 ± 0.01 Å [2]. It is formed by mixing the CsCl and $HfCl_4$ in stoichiometric ratio 2:1 and congruently melting at ca. 826 °C. Calculations of self-trapping of holes and electrons in the form of V_K and polarons centers in the Cs_2HfCl_6 matrix were presented [3] and confirmed by EPR measurements [4]. In this work we report on the growth of Cs_2HfCl_6 single crystals by the vertical Bridgman method. Absorption, radioluminescence (RL), photoluminescence (PL) excitation and emission spectra as well as PL decay of prepared single crystals were evaluated. Temperature dependence of the PL and PL decay were measured in wide temperature range. Scintillation performance was characterized by measuring the light yield and scintillation decay. Analysis of the measured RL and PL data using Gaussian fitting was performed.

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Tuesday, 11 September 2018, 16:15-18:00 P32-Tue

EPR study of Ce^{3+} luminescent centers in the $LuAlO_3$ single crystalline films

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Ce^{3+} doped yttrium and lutetium aluminum perovskites, $Y(Lu)AlO_3$ (Y(Lu)AP), are well-known scintillating materials. Among the other defects studied in these hosts, the $Y(Lu)_{Al}$ antisite defects (AD), oxygen vacancies and their aggregates with impurities are particularly important [1]. The lattice defects number can be significantly reduced in the single crystalline films (SCF) grown using low-temperature liquid phase epitaxy method [1]. However, the SCFs can contain the components of flux which may affect their properties [1]. Correlation of traditional optical and luminescence methods with electron paramagnetic resonance (EPR) provides a unique possibility for correct interpretation of the luminescent properties of such oxides.

In this report we present results of EPR investigation of the Ce^{3+} incorporation in the $LuAlO_3$ (LuAP) single crystalline films, grown by LPE method from the melt solution based on the PbO-B_2O_3 flux onto undoped YAP substrate. The thickness of the SCF sample was 20 mm. The EPR measurements were performed at X-band (9.4 GHz) of microwaves in the temperature region 10-296 K using the commercial Bruker E580 spectrometer.

EPR spectra measured in two LuAP:Ce film samples, grown in the [010] direction onto YAP substrate, demonstrated the presence of Ce^{3+} resonances similar to the reported earlier in bulk material [2]. To distinguish the signals coming from the films and the substrate, the latter was measured separately. The dominating Ce^{3+} resonance lines originating from the films (about 98% of the overall cerium spectral intensity) were accompanied by the satellite signals attributed to the pairs of coupled Ce^{3+} ions [3]. Besides, the EPR spectra contained also signals from the Mo^{5+} and Pb^{3+} impurity ions.

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Electrical and optical properties of β-Ga_2O_3 and β-Ga_2O_3:Ce crystals

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β-Ga_2O_3 represents a candidate for a new fast and efficient semiconductor scintillator. It has been demonstrated that already an unintentionally n-type doped crystal exhibits some promising scintillation properties [1,2]. Moreover, plenty of room for further improvement can probably be found in doping of β-Ga_2O_3 with various elements like tin [3] or cerium [1,4]. All the mentioned works, however, should be considered as preliminary steps, showing some initial results, with no in-depth understanding of the physics that stands behind.

In this communication we focus on β-Ga_2O_3 and β-Ga_2O_3:Ce crystals grown by the Czochralski method at Leibniz Institute for Crystal Growth in Berlin [5]. The performed investigations, which include such techniques like Hall measurements, DLTS (Deep Level Transient Spectroscopy), cathodoluminescence, and X-ray fluorescence, have been aimed mainly at determining the influence of the presence of cerium on electrical and optical properties of β-Ga_2O_3. The preliminary results might expand our knowledge on the scintillation process in semiconducting β-Ga_2O_3, whether pure or intentionally doped with cerium and/or other dopants, what is crucial in a further development of that compound for scintillation purposes.

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Thermoluminescence measurements and a possible new zeroing mechanism of the corresponding signal in mineral and commercial gypsum samples

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Gypsum is a widely mined sulfate mineral composed of calcium sulfate dihydrate, with the chemical formula $CaSO_4.2H_2O$. Among the plethora of its applications, the most important is being the main component of art objects such as sculptures, as well as the ground layer of portable and wall paintings. Polymeris et al. [1] have presented preliminary thermoluminescence (TL) glow curves measured for one commercial gypsum sample manufactured and customarily sold in the market by ABIO Products, Asser Brynie. In the framework of the present study, preliminary TL results are studied and presented for a number of both mineral and commercial samples of gypsum, and also other Ca-sulfates (bassanite and anhydrite) [2,3].

Dosimetric properties such as the stability of the TL peaks, the zeroing mechanisms and the prevalence of these, are quite important in a feasibility study of gypsum as an alternative dating dosimeter. The study includes TL features, such as TL glow curve shapes and the calculation of the kinetic parameters of TL peaks, in an effort to estimate the lifetimes of each trap. Moreover, there are experimental hints that mixing gypsum with water is an effective zeroing mechanism for the TL signal. The validity of this feature is also being studied for various samples. The primary aim of this work is to study whether these aforementioned TL features are prevalent over all samples. In addition, a structural and compositional characterization was performed using FTIR, XRD and SEM-EDS techniques.

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Silica optical glasses produced from quartzite of East Sayan Mountains

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Natural raw quartz is widely employed to obtain quartz concentrates of high and ultrahigh purity. Optical quartz glass is produced with these concentrates for visible spectrum areas and those close to the infrared spectrum, as well as thermostable quartz ceramics with their broadest application. Rock crystal and veined quartz of various geological and commercial types are traditionally utilized to produce quartz concentrates of high and ultrahigh purity. Quartz vein bodies contain only limited reserves, and they demonstrate a highly heterogeneous pattern of distribution. The quartzites surveyed at the Bural-Sardyk deposit of the East Sayan Mts prove to be highly homogeneous and pure [1-2].

The textural and structural features and mineral and fluid inclusions are determined for all types of raw quartz material. The fluid inclusions in high-purity saccharoidal and super quartzites are largely distributed within available fractures and intergranular space, and only in places within the aggregates. In compact quartz, the fluid inclusions occur inside quartz grains, and at times within intergranular space.

The production schemes have been developed for each type of high-purity quartz concentrates. The procedure consists of disintegrating the lump in a jaw crusher with tungsten carbide jaws to reach 25 mm fraction; classifying into a fraction of 5-25 mm; chemical etching of the lump with 10 % HCl solution; lump drying; thermal disintegration; manual disintegration in a quartz mortar to obtain 5 μm fraction; grinding in quartz grinder; and separating of 100-300 μm and 174-450 μm fraction and chemical beneficiation in 20% HCl-10% HF mixture at 2:1 solid-to-liquid (S-L) ratio. Additionally, the compact quartz grit is annealed in a vacuum at 1450^{o}C for 3 hours for opening fluid inclusions and chemical beneficiation. Deep and ultra-deep beneficiation of quartz concentrates were obtained for all types of quartzites.

Quartz glass samples were produced from the beneficiated quartz concentrate by vacuum compression fusion in a graphite crucible under 5 bar pressure. The spectral analyses indicate that produced glass samples possess high light-transmission capacity in a broad spectral range. The adsorption spectra of obtained samples within 2700-2800 nm do not show the band related to the OH-group adsorption.

Synthesis, luminescent and dosimetric properties of anion-defective ceramics based on Al_2O_3-BeO

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Luminescent detectors of ionizing radiations on the base of aluminum oxide (α-Al_2O_3) and beryllium oxide (BeO) are successfully used today to solve different dosimetry tasks. However, the upper limit of the linear range of the registered doses for this detectors is not higher than 1-10 Gy. This fact makes it difficult to use such detectors when the absorbed dose can be 0.1-100 kGy. TL detectors based on the materials synthesized from nanopowders, in particular on the base of anion-defective alumina ceramics are promising to measure such doses [1]. Nevertheless, the task of developing luminescent detectors for high radiation doses cannot be considered completed, thus new materials are being searched for high-dose measurements.

Introduction of other oxides into the matrix with the formation of ceramic composites is one of the ways to modify the luminescent properties of alumina. The aim of this work is to synthesize and study luminescent and dosimetric properties of anion-defective Al_2O_3-BeO composites and the possibility of using them to register high doses of ionizing radiations.

The samples of α-Al_2O_3 compacts were made of precursor nanopowders (75-200 nm) by using cold uniaxial pressing. Anion-defective Al_2O_3-BeO ceramics were synthesized by high-temperature treatment of Al_2O_3 compacts (1500 ^{o}C, 4 hours) in vacuum in beryllia crucibles with the presence of carbon. A method of X-ray diffraction revealed new phases of BeO with the concentration about 30%. The presence of oxygen vacancies in Al_2O_3 lattice of the obtained ceramics was confirmed by measuring pulsed cathodoluminescence.

The TL curve of the obtained ceramics exposed to a high dose of gamma-radiation (100 Gy) featured an isolated peak at 250 ^{o}C, which was close to the TL maximum in additively colored BeO crystals. The absence of the TL thermal quenching is an advantage of ceramic composites over Al_2O_3 and BeO. An analysis of TL kinetics by using Tm-Tstop method showed the presence of energy distribution of the traps responsible for the TL peak. The parameters of this distribution were found by initial rise method and fractional glow technique. The linearity range of TL dose response of the obtained ceramics under gamma-irradiation is 10-300 Gy. Dispersion of TL sensitivity in the set of the samples synthesized during one technological cycle is not higher than 10%. The obtained results show that the synthesized composite Al_2O_3-BeO ceramics are much better in the upper limit of the registered doses than Al_2O_3- and BeO-based commercial detectors and are not worse than ultrafine Al_2O_3 ceramics [1]. Moreover, they are superior to the latter in a number of other characteristics.

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The influence of optical bleaching following irradiation on the dose response of TLD-100

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The influence of optical bleaching following irradiation on the dose response of TLD-100

The thermoluminescent dosimeter, LiF:Mg,Ti (TLD-100), is widely used to determine patient doses in radiation diagnostics and external beam radiotherapy. The dose range of interest for radiotherapy is 1-5 Gy [1]. In intraoperative electron radiation therapy the applied radiation dose can be as high as 30 Gy [2]. Unfortunately, the thermoluminescence (TL) response of composite glow peak 5 in TLD-100 is non-linear (supralinear) above 1 Gy [3] reaching values of f(D) (the normalized response) as high as 1.15- 1.2 at 10 Gy and 1.5-1.6 at 30 Gy [3]. The supralinearity is thus a significant drawback which requires careful calibration and correction procedures for precision applications. Optical bleaching following irradiation has the potential of changing/reducing or even eliminating the supralinearity due to the alteration of the charge concentrations in the trapping centers (TCs) giving rise to the TL. We have recently tentatively identified the e-only occupied and electron-hole (e-h) occupied spatially correlated TCs and luminescent centers (LCs) at 3.8 eV and 4.3 eV respectively in the optical absorption spectrum which give rise to glow peak 5 [4]. It is expected that photon bleaching at selected energies will increase the relative concentration of the e-h to the e-only configuration and thereby reduce the supralinearity due to the geminate nature of the e-h recombination in which competitive processes are subdued [5]. In addition selective bleaching may decrease the population of the 5.45 eV band correlated with the competitor to peak 5 which may also decrease the supralinearity. Preliminary experiments are underway.

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Luminescence processes in lanthanide-activated lithium aluminoborate glasses and glass ceramics

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Borate glass represents a promising matrix system in the development of temperature-stable phosphors for solid-state lighting. After optical activation by the addition of lanthanide ions, borate glass provides a bright luminescence in the visible spectral range upon appropriate excitation in the ultraviolet/blue spectral range. To overcome the problem of the weak optical absorption coefficients of the added lanthanide ions and to increase the optical path length for the excitation light, the as-made glass is processed to a glass ceramic. The amount of crystallites grown in the glass is controlled by appropriate choice of annealing time and temperature.

In this work, the luminescence processes in lanthanide-free as well as in lanthanide-activated lithium aluminoborate glasses and glass ceramics are investigated by UV-Vis spectroscopy, x-ray diffraction and VUV photoluminescence spectroscopy. The latter experiments are carried out under synchrotron radiation excitation at the FinEstBeAMS of the MAX IV 1.5 GeV storage ring. Both, excitation and emission spectra, are studied. Thermal processing of the as-made glass to a glass ceramic results in emerging of a broad emission band in the ultraviolet spectral range. This emission is tentatively attributed to an excitonic emission from the increasing number of crystallites in the glass matrix. For the lanthanide-activated series, also the lanthanide-related emission bands in the visible spectral range increase in intensity upon prolonged thermal processing.

Luminescence and scintillation properties of rare-earth-doped LaAlO3 single crystals

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Scintillation materials based on inorganic single crystals have been employed in the ionizing radiation detection and related fields for several decades [1]. They are utilized in high-energy physics, environmental monitoring, industrial defectoscopy, geological survey and oil well logging, astronomy and other fields of scientific or other research. Due to the international situation, the security monitoring applications have rapidly emerged as well. Aluminum perovskites represent an important group of promising scintillation materials [2], but due to a difficulties in crystal growth, not much attention has been paid to them so far. The reported decay time of the Ce -doped $YAlO_3$ (YAP) luminescence is as short as 18 ns, which makes it one of the fastest materials among the Ce -doped oxide scintillators [2]. Furthermore, YAP:Ce shows very small nonproportionality of the scintillation response, which results in its excellent energy resolution. High energy resolution can be very important for some of the mentioned applications, such as medical imaging or environmental monitoring, where hihg-energy photons of close energies need to be resolved.

However, the growth of YAP single crystals is still quite difficult due to a strong tendency of the yttrium-aluminum garnet (YAG) phase creation. Therefore, we decided to study its compositional analogue $LaAlO_3$ (LaAP), the growth of which is easier due to the stabilization of its phase by a large La^{3+} cation in the material structure.

We have prepared the rare-earth-doped (Ce^{3+}, Eu^{3+}, Tb^{3+}) LaAP crystals by a micro-pulling-down method. The XRD analysis revealed that the crystal consists of a rhombohedral low-temperature LaAP phase.

Crystal growth will be briefly reported together with luminescence and scintillation properties and interplay of the luminescence phenomena. Preliminary sketch of the luminescence mechanism will be also presented and discussed.

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Luminescent properties of cerium-doped YSO/ LSO /LYSO microcrystals prepared via room temperature sol-gel route

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Rare-earth-doped yttrium orthosilicate (Y_2SiO_5, YSO), lutetium orthosilicate (Lu_2SiO_5, LSO) and their solid solution (Lu,Y_2SiO_5, LYSO) as bulk materials are commonly used in diverse applications, such as LED phosphors [1], high energy physics [2], security inspection, medical physics and many others [3,4].

In this work we demonstrate preparation of YSO/ LSO /LYSO microcrystals at room temperature using sol-gel technique. Structural properties of the materials were characterized by X-ray powder diffraction. The average crystallite size was determined using scanning/transmission electron microscopy. We also studied the changes in luminescent properties after the reduction of particle size by grinding in a ball mill. Radioluminescence spectra show that luminescence intensity of the phase containing smaller particles after fractionalization procedure remains the same when compared to the as-prepared material. Furthermore, it was observed, that milling process leads to the acceleration in the photoluminescence decay time.

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Formation of MI_2:Eu (M = Ca^{2+}, Ba^{2+}, Sr^{2+}) fine powders for scintillation detectors

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Nowadays there is a large variety of scintillation materials. Among them iodides of alkaline earth elements doped with Eu^{2+} are attractive for use because of their high LY (up to 120000 ph/MeV) and energy resolution (up to 3% at 662 keV). However, structural anisotropy and high hygroscopicity make difficult their production in the form of large single crystals. Ceramics or glass ceramics can be an alternative to single crystals due to weak effect of structural anisotropy and hygroscopicity. All the approaches that are used for single crystals, ceramics and glass ceramics manufacturing require the development of methods for the synthesis of initial compounds in the form of powders. In accordance with the foregoing the development of the synthesis methods of MI_2:Eu (M = Ca^{2+}, Ba^{2+}, Sr^{2+}) in the form of powders is actual and has practical interest.

In present work we demonstrate the original approach for the synthesis of the MI_2:Eu (M = Ca^{2+}, Ba^{2+}, Sr^{2+}) powders, which is the same to BaI_2:Eu that was demonstrated earlier by us [1]. This approach involves two stages: the precursor preparation and its heat treatment in the atmosphere of the iodinating agent. By now the possibility of transferring this method to the CaI_2:Eu and SrI_2:Eu has been shown.

The main feature of the proposed approach is the $Eu^{3+} \rightarrow Eu^{2+}$ transition implementation in the synthesis process without the use of a reducing atmosphere. Furthermore, the possibility of the particles morphology control by variation of the synthesis conditions and its influence on luminescent properties of MI_2:Eu (M = Ca^{2+}, Ba^{2+}, Sr^{2+}) powders have been established.

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Recombination luminescence in CaSO4

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Sulfates of alkaline earth metals (AEM) are used as thermoluminescent dosimeters. In these systems, the thermoluminescence arises as a result of recombination of Frenkel defects. It is known that defects in irradiated sulfates of AEM arise as a result of the localization of electrons and holes on anionic complexes or specially introduced impurities. Such defects as oxygen vacancies, an interstitial atom, or an oxygen ion appear in the decay of excited anionic complexes $SO_4{}^{2-}$. It is assumed that dosimetric peaks of TSL in AEM sulfates activated by rare-earth ions should arise when electronic centers of the type $SO_3{}^{-}v_a{}^{+}$ e^{-} recombine with hole centers-interstitial oxygen localized in the cation vacancy. In irradiated sulfates of AEM, there are two types of electronic excitations that relax radiatively or with the formation of defects. The first is the excited anionic complexes $SO_4{}^{2-}$. The second is the electronic excitation that occurs when electrons move from the valence band to the conduction band. As a result of the relaxation of these electronic excitations in the sulfates of AEM, radiation defects and recombination radiation are created. The mechanisms of creation of anion vacancies, interstitial atoms and oxygen ions have not been studied.

We have shown that when X-rays, photons with energy 5-6 eV, and UV photons with energy 9-11 eV are irradiated, peaks of TSL with different efficiencies are created, approximately in the same temperature range. In this process hole-centers, which are interstitial oxygen atoms, correlated with electron capture centers can be created. Defect formation during excitation by low-energy photons with energy 5-6 eV was discovered by us for the first time. Earlier, we have shown for alkali metal sulfates that the spectral composition of the TSL peaks corresponds to intrinsic recombination emission. Our research has shown that the intrinsic recombination luminescence in $CaSO_4$ in spectral position coincides with the emission arising when excited by X-rays and photons with energy 6-11.5 eV. A possible mechanism of energy transfer in a $CaSO_4$-RE crystal from an excited anionic complex $SO_4{}^{2-}$ to rare-earth impurities is discussed.

Blue-Emmitting $CsPbBr_3$ Nanocrystals with Ultrafast Decay

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In 2015, Protesescu et al. [1] developed a hot injection method for synthesis of caesium lead halide nanocrystals with general formula $CsPbX_3$ (X = Br, Cl or I). The main advantages of this material are the outstanding photoluminescence properties (high quantum yield, narrow emission line widths and short radiative decay) and easy tunability of the emission spectra over the entire visible spectral region. These advantages make it an excellent candidate for the optoelectronic applications, namely photovoltaics and LEDs. Due to this, the synthesis and characterisation of these nanocrystals is rapidly growing field of research. We focused on $CsPbBr_3$, featuring a known bright green emission band around 500 nm which can be blue-shifted due to the quantum confinement effect down to 400 nm [2]. We use much simpler synthesis method than the widely used hot injection, based on the procedure reported by Li et al. in 2016 as the supersaturation recrystallization [3]. The advantage of this method over the hot injection is no need for neither elevated reaction temperature, nor the inert gas protection. Instead of the photovoltaics, we concentrate on the possibility to use this material as a detector for the time of flight positron emission tomography (TOF PET). Our photoluminescence decay measurements show an ultrafast component with the decay time of 320 ps, which is highly promising for this application. We also suggest a core-shell structures which can protect the material from the air oxygen and moisture, and therefore allow the $CsPbBr_3$ nanocrystals to be used as detectors.

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Garnet based complex substituted glass ceramic materials

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Ce^{3+} doped garnets are widely used as phosphors in different fields: from solid state lighting to scintillation detectors. Garnets engineering is reached by replacing cations in garnet structure on other, which differ from the substituted ones with unchanged garnet structure. This leads to change of “metal-oxygen” bond length and consequently affects the luminescence properties of rare-earth ions due to distortion of their crystalline surrounding. For example, the spectacular improvement of the scintillation light yield was shown for modified garnets obtained by partial substitution of Al^{3+} on Ga^{3+} in MAG:Ce (M=Y^{3+}, Gd^{3+}, Lu^{3+}), substituted garnet. Fast timing scintillation was demonstrated for complex substituted garnet based on the $Gd_3(Ga,Al)_5O_{12}$:Ce, where part of Al^{3+} was substituted by Ga^{3+}.

Heterovalent substitution is another approach to obtain new compounds with garnet structure. Partial substitution of Y^{3+} and Al^{3+} by Mg^{2+}/Ca^{2+} and Si^{4+} or Ge^{4+} respectively in the YAG:Ce is interesting to obtain the garnets with the glass forming elements, namely Si^{4+} or Ge^{4+}. Such substituted garnets were synthetized in glass ceramic form.

In the first step, the $Y_2CaAlGe(AlO_4)_3$:Ce (YCAGG:Ce) and $Y_2MgAlGe(AlO_4)_3$:Ce (YMAGG:Ce) garnets powders by using co-precipitation technique were prepared. In the second step, the YCAGG:Ce and YMAGG:Ce garnets were grown in a bit off-stoichiometric glasses by their homogenous crystallization. For the glass ceramic samples only the reflections for garnet phase were found a bit shifted as compare to the powders in XRD patterns. This proofs the YCAGG:Ce and YMAGG:Ce crystallites formation in glass matrix. Habitus of crystallites was typical for garnet structure. PL mapping of the glass ceramics surface showed that the crystallites are optically inhomogeneous and have layered structure which is most likely due to the change of local composition of the glass during the crystallites growth.

Similarly, the glass ceramics based on the substituted $Y_3Al_5O_{12}$:$Eu^{2+,3+}$, $Gd_3Ga_2Al_3O_{12}$:Ce, and $Gd_3Al_2Ga_3O_{12}$:Ce garnets were obtained.

Persistent luminescence of Ti-Doped $La_2Hf_2O_7$

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Lanthanum hafnate, $La_2Hf_2O_7$, due to high density of 7.9 g/cm^3, and the presence of Hf with Z=72 provides high stopping power for X- and γ-rays. $La_2Hf_2O_7$ exists in just one crystal structure - cubic pyrochlore, space group *Fd-3m* and a=10.785 Å [1]. With such properties lanthanum hafnate is considered a potentially good matrix for novel high energy radiation detectors - scintillators and X-ray phosphors. In the past the spectroscopic investigation of $La_2Hf_2O_7$ doped with such ions as Eu^{3+}, Tb^{3+}, Pr^{3+}or Ce^{3+} proved that the matrix is able to transfer the gained energy to the dopants and produce luminescence of significant intensity [2-7].

The presentation shows the concentration and temperature dependence of spectroscopic properties of Ti-doped $La_2Hf_2O_7$ powders. Compositions with different activator amounts were heat-treated at various temperatures, atmospheres and also converted into sintered ceramics.

Temperature dependence of photo- as well as radioluminescence was studied. Both optical and X-ray excitation of $La_2Hf_2O_7$:Ti produced a blue emission resulting from the activator ion radiative relaxation. All samples exhibited a blue afterglow following UV excitation. For that reasons thermoluminescence properties of $La_2Hf_2O_7$:Ti were investigated and will be analyzed.

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Growth of Cs2HfCl6 single crystal by vertical Bridgman method and characterization of its optical and luminescence properties

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Cesium hafnium chloride of formula Cs_2HfCl_6 (CHC) was discovered as a scintillating material by Bryan and Ferranti in 1984 [1] and recently it was identified by Burger et al. [2] as a promising scintillator for gamma spectroscopy. Its high stopping power (Z_{eff} = 58 and density of 3.86 g cm^{-1}), low hygroscopicity, light output around 54 000 ph/MeV, and energy resolution of 3.3 % at 662 keV in the undoped single crystal make it a suitable candidate for high resolution cost effective gamma spectrometers.

CHC is formed by congruent melting of a stoichiometric mixture (2:1) of CsCl and $HfCl_4$. CHC crystalizes in cubic structure with lattice parameter $a = 10.42 \pm 0.01$ Å [3]. However, the preparation of CHC and its subsequent crystal growth is complicated due to a low sublimation temperature (at ca. 320 °C) and high hygroscopicity of $HfCl_4$. High purity starting materials are imperative for successful growth of CHC single crystals. Therefore, development of a purification procedure was required. Multiple resublimation of $HfCl_4$ and introduction of halogenating agents into molten CsCl followed by a zone melting were applied.

The aim of this work is a preparation of high quality and purity CHC material and its subsequent crystal growth by vertical Bridgman method. Prepared crystals were characterized using X-ray fluorescence and X-ray diffraction analyses to determine the purity and phase content, respectively. Moreover, the optical characterizations: the absorption, radioluminescence, and photoluminescence spectra as well as decay measurements on prepared optical specimens from grown crystals were performed.

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On nature of deep traps responsible for thermoluminescence of YAP:Mn crystals above room temperature

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Mn-doped $YAlO_3$ (YAP) is of interest as a material for thermoluminescent (TL) dosimetry of ionizing radiation. In particular, the green emission near 530 nm from Mn^{2+} ions occurrs in the main TL peak at 200 °C. Besides, an orange emission around 640 nm occurs in the TL peak near 350 °C.

The recharging processes occurring with Mn^{4+} or Mn^{2+} ions under irradiation and next recombination processes during warming of the irradiated crystal are not recognized unambiguously. The possible trapping processes here are even more questionable. The fact that intensity of the TL peak at 200 °C increases substantially with increasing of non-stoichiometry of the crystal (excess of Y over Al) [1] clearly indicates that that these traps should be related to Y_{Al} antisites in YAP structure.

In order to get a better insight into the recharging processes the Mn^{2+} ions are involved in YAP lattice, the detailed EPR studies of the YAP crystals doped mainly with Mn^{2+} ions and containing access of yttrium over aluminum have been performed. Purpose of the present work was to perform the EPR analysis of such YAP:Mn^{2+} crystals and to correlate the obtained results with the results of luminescence and optical absorption studies of this material performed before.

The performed EPR analysis testifies one type of centers having rhombic point symmetry with one of the principal axes coinciding with the crystal's *c*-axis and the other two lying in the *ab* plane. It was revealed that the Mn^{2+} ions undergo recharging under ionizing irradiation and restore to their previous level only after subsequent warming at about 400 °C. Based on the presented results and the thermosluminescence results obtained before, the trapping and recombination mechanism observed in the material above room temperature are discussed.

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Luminescent properties of $CeAlO_3$ crystals and phase-separated $CeAlO_3/CeAl_{11}O_{18}$structures

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Our report presents the results of the investigation of luminescent properties of $CeAlO_3$ crystals and phase-separated $CeAlO_3/CeAl_{11}O_{18}$ structures under excitation by e-beam, α-particles and high-energy X-ray quanta. $CeAlO_3$ bulk crystals and $CeAlO_3$-$CeAl_{11}O_{18}$ based metaphase materials were grown on a $CeAlO_3$ seed by the Edge Defined Flux Grown method from W-crucibles under the Ar + CO reducing atmosphere [1].

The luminescence in $CeAlO_3$:Ce crystals under excitation by high-energy X-rays, e- beam and α-particles was registered first time. The observed luminescence in $CeAlO_3$ crystals in the double bands peaked at 446 and 500 nm is probably related to Ce^{3+} 5d-4f transitions in $CeAl_{11}O_{18}$ phase, which is present in crystals as an admixture. The scintillation light yields of $CeAlO_3$ crystal under α-particles is equal about of 12 % in respect to standard YAG:Ce sample.

Due to the fact that the $CeAlO_3$ single- and poly-crystals possess very weak luminescence in the room temperature range under soft X-rays and γ-radiations, this material can be promising for selective registration of high-energy particles.

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Fast scintillators for high energy physics and medical applications

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The recent years have seen an increasing need of fast timing detectors for various application domains. Typical examples for the use of precise time stamping are the need to disentangle scattering events in closely spaced bunch trains in future high luminosity accelerator experiments as well as to identify space points on the conventional lines of response reconstructed in positron emission tomographs (PET), both requiring a major leap forward in the improvement of timing precision significantly below 100ps. Bringing the timing resolution of radiation detectors down to the 10ps level will thus bring dramatic benefits in terms of image quality and reconstruction time in the health sector and in tems of detection efficiency for HEP. Reaching this goal requires technical breakthrough in all key elements of the detection chain such as scintillators, photodetectors and readout electronics. Over the last years, in the frame of Crystal clear collaboration with the support of several European projects, various studies have been carried out addressing all aspects of understanding and improving the key parameters of fast timing detectors and to develop new innovative concepts of future radiation detectors. In the domain of scintillation detectors, various ultra fast scintillation processes have been investigated. In this presentation, we will present the current state of art of time resolution and the different approaches pursued to go forward 10ps time resolution.

Latest advances in aluminum oxide OSL materials and instrumentation

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The optically stimulated luminescence (OSL) technique has already become a successful commercial tool in personal radiation dosimetry, medical dosimetry, diagnostic imaging, geological and archeological dating. This presentation describes the fundamental principles and latest advances in OSL materials, readout technique and instrumentation.

Known for decades OSL became a successful commercial dosimetry technique after development of a very sensitive aluminum oxide (Al_2O_3:C) luminescent material and pulsed-OSL (POSL) technique. In contrast to TL, OSL is an all optical technique that does not require detector heating and recently developed super bright light emitting diodes (LED) allow very simple and compact OSL reader design. Due to high luminescence sensitivity of OSL materials one does not need to empty all dosimetric traps at once. Precise delivery of stimulation light allows multiple re-reads with the same precision and with minimal depletion of traps. As a result a fast and almost non-destructive readout is implemented. Because heating of the OSL dosimeter is not required, there is no such a detrimental effect as "thermal quenching" of luminescence and one can implement a simple badge design by using powder in plastic manufacturing process with million of OSL detectors having the same sensitivity. High resolution imaging using OSL is already widely used in digital radiography and OSL imaging and image processing was successfully implemented to discriminate static and dynamic irradiation condition and to investigate the abnormal irradiations in personal monitoring.

Our latest achievements include new high uniformity Al_2O_3:C OSL film with fine grain powder and aluminized lamination. New compact optical engine with optimized LED position, light focusing optics and improved emission filtration resulted in doubling of radiation sensitivity up to 8000 counts/mSv at only 1% depletion.

Significant new developments of new OSL instrumentation will be reported. Existing medical OSL reader Microstar-ii was upgraded with the new optical engine and re-engineered drawer for loading OSL NanoDots that allows one to achieve less than 1% reproducibility in repetitive measurements, which is extremely important in dose verification during therapeutic radiation treatment or QA program.

New automatic OSLR reader utilizing the new optical engine, modern electronics design, new software and having different loading capacity (50, 250 and 700 badges) will be described. Radiological performance parameters of the new reader with the latest generation of GN-type of OSL dosiemter will be presented.

Fluorescent imaging of heavy charged particle tracks with LiF single crystals

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Lithium fluoride is a very well-known thermoluminescent material, widely applied in ionizing radiation dosimetry. LiF shows also interesting radio-photoluminescence properties. Radiation creates in LiF crystals various defects, including F_2 and F_3^+ color centers. F_2 center is composed of two anion vacancies with two bounded electrons, while F_3^+ of three vacancies with two electrons. Both these centers have overlapped absorption bands peaked around 440-450 nm, while the photoluminescence emission spectrum exhibits two peaks at about 670 nm (related to F_2) and about 520 nm (related to F_3^+).

Recently photoluminescence of of F_2/F_3^+ centers in LiF was successfully exploited for imaging of tracks of single nuclear particles [1, 2]. LiF single crystals were grown with the Czochralski and micro-pulling down methods at IFJ PAN. The crystalline samples were irradiated with various radiation modalities: alpha particles, thermal and fast neutrons, as well as quite recently with high-energy ion beams at the HIMAC accelerator in Chiba (iron, neon and carbon beams). Fluorescent images of nuclear particle tracks were then obtained under blue light excitation, using a wide-field fluorescent microscope equipped with a high-sensitive CCD camera. The lateral resolution of the images was found to be below 0.5 μm, while axial below 1 μm.

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Characterization of scintillators and optical components for the ESS Target Imaging System

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The European Spallation Source (ESS), currently under construction in Lund (Sweden), will be the world's most powerful source of neutrons used for research. The source of the neutrons is a rotating 2.5 m diameter wheel containing about 6500 tungsten bricks, encased within a steel shroud; this is new technology, and the integrity of the internal components needs to be continuously monitored, watching for damaged or dislodged bricks. Producing an image of the bricks within the wheel can only realistically be achieved using decay gamma photons from the activated tungsten bricks.

The proposed design for the gamma camera is based on a linear array of scintillators, radial to the wheel, with imaging achieved via a bespoke push-broom method. This Target Imaging System (TIS) comprises a 2.8 m long collimator with 500 scintillator crystals ($1\times1\times10\text{mm}^3$) individually coupled to 20 m long optical fibers; the scintillation light is read out by means of an intensified sCMOS (I-sCMOS) camera [1].

While the I-sCMOS camera is located away from the target monolith in a low-radiation environment, the scintillator crystals and the front end of the optical fibers are placed in the high-radiation environment of the ESS target monolith; the radiation comprises: a) prompt gamma photons and neutrons generated during the spallation process, and b) delayed gammas from activated components within the target monolith.

In this study, we characterize the scintillators and optical components of the TIS under neutron and gamma irradiation mimicking the intense radiation fields of the ESS target monolith. This includes neutron activation, afterglow after irradiation, degradation of the detection efficiency and the possibility of recovery, and the generation of parasitic blue/UV light in the optical fibers. These measurements will allow to identify suitable components, optimizing the TIS, and estimate expected lifetime and/or maintenance schedule of the TIS.

Measurements are carried out at the Technical University of Denmark (Roskilde, DK) and at Paul Scherrer Institut (Villigen, CH).

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Improving light collection of scintillating crystals using photonic crystals

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Inorganic scintillators are widely used in radiation detection and imaging instruments that are vital in high energy physics, medical imaging, industrial and homeland security applications for the detection, localization, and energy determination of X-rays, γ -rays, or neutrons. For all applications it is important to have a high energy resolution and a high time resolution for which the light extraction efficiency from the scintillator is a key parameter.

One of the challenges of light extraction from inorganic scintillating crystals, is the large difference in index of refraction between the crystal and the coupling material. Even while coupling with an optical coupling agent and using wrapping on the non-readout surfaces, in some crystal geometries up to 50% of the scintillation light can be trapped inside the crystal.

We will present how this light could be accessible when applying photonic crystal slabs, thin dielectric layers with a periodical 2D or 3D nano-structure, to the scintillators readout surface .

We will present simulations used to design optimal crystal photonic patterns, production methods of the photonic crystal slabs and characterization of scintillator with photonic crystal slab on the readout surface. Results on gain in extracted light yield and time resolution will be presented.

Recent progress in the development of composite scintillators based on the single crystalline films of garnet compounds

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The report presents the short review of our last achievements in the development of composite luminescent materials based on the single crystalline films (SCF) and single crystals (SC) of simple and mixed garnet compounds using the liquid-phase epitaxy (LPE) method for application as scintillating materials for radiation monitoring of mixed ionization fluxes and microimaging.

The main topic of research is connected with the development of **multilayer composite scintillators** based on SCFs and SCs of garnet compounds for simultaneous registration of different types of ionizing radiations in mixed ionization fluxes of particles and quanta. Such composite scintillators have been made in the form of multilayer epitaxial structures containing one or even two SCF scintillators grown by the LPE method onto substrates from SC scintillators [1, 2]. Films and crystal parts of composite scintillators can be fabricated from effective scintillation materials on the basis of (i) Ce^{3+}, Pr^{3+} and Sc^{3+} doped $Lu_3Al_5O_{12}$garnets [2] as well as (ii) the Ce^{3+}doped $Gd_{3-x}A_xAl_{5-y}Ga_yO_{12}$ mixed garnets, where A= Lu, Tb and La; x=0-1; y=2-3 with signficantly different scintillation decay kinetics [1].

The report presents the brief results on fabrication of composite scintillators based on the above mentioned garnet compounds by LPE method as well as the results of investigation of their luminescent and scintillation properties. The testing of the developed CSs in the detectors for radiation monitoring of α- and β-particles and γ-quanta were performed and the obtained results are analyzed for the choice of most efficient types of composite scintillators.

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Evolution of track structure and its influence on scintillation characteristics: decay profile, non-proportionality and energy resolution

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Interrelation between scintillator parameters (decay profile, non-proportionality and energy resolution) and material properties is not a straightforward one and requires a deeper understanding of collective processes in track region. Most scintillation properties are defined by the spatial distribution of electronic excitations in the track region and evolution of this distribution with time. Spatial distribution of excitations can be described in the simplest case by the weight function, which represents the probability for an excitation (electron, hole, exciton, etc.) to be surrounded by other excitations with a local concentration n. This weight function can be calculated as the convolution of 1D distribution of energy losses along the track with 3D distribution of excitations due to their spread during thermalization. The resulting concentrations n can have the values from 10^{12} cm^{-3} away from the trajectory of ionizing particle to 10^{22} cm^{-3} at the track end and in the centers of clusters of excitations. The most probable concentration and the shape of this weight function depend on the properties of scintillator material and the energy and type of ionizing particle. Moreover, this distribution can fluctuate from one track to another due to the effect of track branching. More detailed description involves not only concentration of different types of excitations but also correlation functions between these excitations.

It is well-known that most of the elementary processes are bi-molecular ones or have even a higher order (like Auger processes) and therefore the processes in the track region with a low concentration of excitations differ significantly from those in the regions with a high concentration. This results in specific features of decay kinetics, yield and even energy resolution of scintillators. Moreover, the evolution of excited region is affected also by defects and different states of activators, especially in low concentration part of the track. Therefore, co-doping could significantly modify the overall properties of scintillators.

The properties of some halide and oxide crystals are analyzed from this point of view together with experimental data obtained for them.

Time-resolved lumenescence z-scan using power fs laser pulses

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A high-energy ionizing particle creates in scintillator structured excited region with concentration of secondary electron-hole pairs from $10^{10}$to 10^{22}pairs per cubic centimeter. It is well-known that density of excitations controls processes of energy transfer, localization of excitations, scintillation yield and decay, storage of energy. High excitation density could result not only in quenching of emission centers, but also can stimulate different processes with superlinear dependence of excitation density. The report presents experimental results for luminescence of wide-band-gap crystals obtained under excitations by harmonics of power femtosecond Ti-Sapphire laserat CELIA (Bordeaux). We study the dependence of processes on excitation density using time resolved luminesence z-scan, the method which allows one to change the excitation density in wide dynamical range and therefore simulate the processes in different parts of the ionizing particle track. The highest density of excitations is achieved under excitation by photons with energy bigger than the forbidden gap energy, when the absorption depth is about few tens of nanometers. Luminescence z-scan was applied for study of exciton-exciton quenching under high VUV harminics (15 to 30 eV) of the Ti-Sapphire laser [1] and fourth harmonics of the same type of laser (6 eV) [2]. In many crystals such quenching starts when the distance between excitations is about Förster energy transfer radius [3], i.e. about 2 to 3 nm. These distancies correspond to concentrations about 10^{20}(e-h)/cm^3, which are achieved in dense parts of track and also can be generated by femtosecond laser. Most studied crystals demonstrate linear dependence of exciton emission on excitation densities below such high intensity of excitation. Nevertheless, some crystals show anomalous nonlinear behaviour of excitonic emission. These results were interpreted in terms of the model of saturated surface losses [2]. We discuss experimental results with such anomalous behavior in ZnO, $CsPbCl_3$and some other crystals. The change of the laser intensity together with z-scan technique allows to expand dynamic range for excitation density to 5 orders of magnitude (from $10^{17}$to 10^{22}(e-h)/cm^3). The dependence on excitation density in $10^{17}$to 10^{19}(e-h)/cm^{3}region shows at least quadratic behavior of the yield in $CsPbCl_3$and ZnO. These obtained results could hardly be explained using saturated surface losses model. The model of creation of multi-particle electronic excitations is presented and discussed.

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Features of YAG and YAG:Ce scintillation crystals grown under CO-containing atmosphere

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New high-energy physics experiments at colliders, as well as future generation of medical tomography equipment need bright scintillators with faster response compared to currently widely used Ce^{3+}-doped scintillators. Ce-doped garnets did not attract much attention until the development of extremely efficient Al/Ga-substituted multicomponent garnets with the light yields of up to 58000 phot/MeV [1]. The improvements in light yield of the latter were attributed to the suppression of electron capture on shallow traps due to the electronic structure modification by cationic substitution [2]. In this sense, it is worth to explore whether it is possible to reduce carrier trapping and improve the scintillation performance in "simple" garnets, such as YAG:Ce, without considering solid solutions with other cations. This can be achieved with a new procedure of growth and post-growth heat-treatment (see [3] and references therein) which causes the incorporation of up to 1 at.% carbon into the crystals.

Absorption, radioluminescence, light yield, and scintillation decay were measured for the set of YAG and YAG:Ce samples. A very high light yield of up to 22700 phot/MeV and a fast luminescence with τ 5 ns was revealed in as-grown colored YAG:C. Air-annealed YAG:Ce,C crystals possess a very high light yield of up to 28800 phot /MeV and a good energy resolution of 8 % at 662 keV.

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The Ce and Li concentration ratio influence on the scintillation and luminescence features in $Gd_3Ga_3Al_2O_{12}$ single crystals

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The Ce^{3+} activated $Gd_3Ga_3Al_2O_{12}$ (GGAG) single crystals are promising candidates for the next generation of the efficient material for scintillator applications, due to very good chemical and physical properties such as high light yield (58,000 ph/MeV), high density (6.2 g/cm^3), short decay time (60 ns), non-hydroscopic character and well mastered single crystal growing technology [1,2]. However, this material suffers from the contribution of the undesired slow component in the scintillation response [3] and long rise time [4]. Recently, the divalent (Me^{2+}) and monovalent (Me^{+}) codoping strategy has been used in order to mitigate the degraded scintillation properties that result from charge carrier traps and have been shown to improve light yield and decay times in some scintillators [5,6].

The motivation for this work comes from the positive impact of stable Ce^{4+} in the GGAG:Ce scintillators. We study the effect of the concentration ratio of Li^{+} and Ce^{3+} in the GGAG crystals on the scintillation and luminescence performance, which is strongly dependent on the stable Ce^{3+}/Ce^{4+} content ratio. The GGAG single crystals with a various dopant (Ce^{3+}) and codopant (L^{i+}) content were grown from the melt by the micro-pulling-down method. They were characterized by optical absorption, photoluminescence excitation and emission and radioluminescence spectra and photoluminescence decay kinetic measurements. Scintillation properties of the crystals were studied by means of light yield value and scintillation decay time measurements.

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Charge trapping and energy transfer in $Y(Lu)_3Al_5O_{12}$:Eu,(Fe) ceramics: EPR and TSL study

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Yttrium and lutetium aluminum garnets ($Y(Lu)_3Al_5O_{12}$, Y(Lu)AG) doped with various rare earth ions like Ce^{3+}, Yb^{3+}, Nd^{3+}, $Eu^{2+,3+}$ are effective light emitting (LE) and scintillating materials. The present work is focused on radiation-induced defects in Y(Lu)AG:(1at.%)Eu ceramics. The influence of different thermal treatments including annealing in air and in reducing Ar:5%H_2 atmosphere is also addressed, together with that of the 50, 200, 1000 ppm iron co-doping. EPR spectra measured in YAG:Eu contained contributions from stable Eu^{2+} paramagnetic ions whereas in the LuAG:Eu the Eu^{2+} resonances were not observed at all. It is worth to note that the Eu^{2+} stabilization in the YAG host was already reported in [1]. The X-ray irradiation at the 77 K temperature does not affect the charge state of europium ions. It evokes charge trapping processes instead. In EPR spectra measured in the YAG:Eu samples, including those after the thermal treatments, only the signal from O^- defect (a hole trap) appears. Comparing its thermal decay and the thermoluminescence (TSL) peak at around 272 K the correlation was found. Iron co-doping causes drastic changes in the TSL glow curve. The 272 K glow peak disappears and the new one appear at approximately 120 K. The EPR spectra of LuAG:Eu display signals originating from different O^- defects as well. The decay of the EPR signals allowed to correlate them to three groups of peaks within the 160-260 K in the TSL glow curve. The only source of emission for any TSL peak in the iron-free samples is Eu^{3+}, whereas in the 200 and 1000 ppm iron doped samples after the thermal treatments the Fe^{3+} emission was also observed.

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Pr^{3+} luminescence for wide-range thermometry

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Luminescence thermometry is one of the "hot" subjects in the research on phosphor materials. A number of important applications - space research, bio- and nanotechnology, medicine, electronics are among them - is a driving force to look for new luminescent materials attractive for temperature reading. Despite a thorough research this field still has difficulty to present luminescent materials offering high sensitivity and accuracy over sufficiently wide range of temperature measuring.

In our presentation we shall discuss the possibility to make a breakthrough in luminescence thermometry combining the specific properties of Pr^{3+} luminescence with so-called band-gap engineering of the host materials. Using Sr_2GeO_4:Pr and its $Sr_2(Ge,Si)O_4$:Pr modifications we shall consider the advantages our approach may offer to this field.

Particle Detection Efficiency of Fluorescent Nuclear Track Detectors in Various Clinical Ion Beams

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Fluorescent nuclear track detectors (FNTD) can play an important role in determining the energy loss and ionization density on a cellular level in clinical ions beams [1,2]. For carbon beams, however, some studies showed that while primary ions can be reliably detected, there is a decreased efficiency of FNTDs for low-LET, light fragments [3,4]. To explore the cause of this effect, we studied the performance of FNTDs for clinical proton, helium and carbon beams under identical conditions. To this end, 21 FNTDs were irradiated at seven specific positions along the depth-dose profile of spread-out Bragg peaks (10-15 cm depth in water) for the respective ion species. Entrance particle fluences were kept at approx. 1.5e6 / cm2 to avoid comprising particle detection due to track overlap. Samples were read-out using a research version of the Landauer FXR700 reader with 2D galvo-scanning. Both imaging times of 10 s and 100 s per 100x100 μm2 image were employed. Track analysis in terms of particle fluence, track intensity (as a proxy for energy loss / LET) and polar angle was done by automated image processing using an in-house Java-based algorithm [5]. Corresponding reference data were generated using the Monte-Carlo particle transport code FLUKA [6,7]. For carbon ion beams it was confirmed that the majority light fragments, esp. secondary protons cannot be reliably detected. In contrast, detection rates for primary and secondary particles agree much closer with the reference data for proton and helium beams even at relatively low LET - if sufficiently long imaging times are used. We conclude that the main reasons for these findings are the presence of primary carbon ions with high fluorescence intensity and the large angular distribution of proton fragments in C beams.

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Luminescence spectroscopy under synchrotron radiation: from SUPERLUMI to FINESTLUMI

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The tuneability of synchrotron radiation and its inherent well-defined time structure makes it particularly well suited for time-resolved luminescence studies. The state of art of such investigations is summarized in the review of *SUPERLUMI* setup of the DORIS III storage ring at DESY [1], which was a flagship for luminescence society for three decades. Many groups have intensively reported the results obtained at the *SUPERLUMI* setup at previous LUMDETR conferences. Since 2012 when the DORIS III ring was shut down, the luminescence society in Europe required for a new luminescence setup as a synchrotron radiation based user facility.

Recently the consortium of Finnish and Estonian Universities developed and constructed the Finish-Estonian beamline (FinEstBeAMS) at MAX IV Laboratory in Lund, Sweden [2]. The MAX IV Laboratory is a new synchrotron radiation research center inaugurated in June 2016. With a circumference of 96 m and electron energy of 1.5 GeV, the new storage ring at MAX IV Laboratory is a perfect synchrotron source for VUV and soft x-ray (XUV) photon generation. The excitation range for this undulator beamline lies between 4.3 and 1000 eV and different filters can be employed to suppress higher orders of excitation. One of the endstations installed at the FinEstBeAMS is the *FINESTLUMI* setup, which is designed for time-resolved luminescence spectroscopy experiments for any type of solid materials. Beamline and endstations are currently in the commissioning phase and regular user access is planned for beginning of 2019.

In the current presentation, we will demonstrate experimental possibilities of the MAX IV facility, FinEstBeAMS beamline as well as technical parameters and characteristics of the *FINESTLUMI* setup. The comparison of the *FINESTLUMI* and *SUPERLUMI* setups will be given in order to provide detailed information for potential users about the advantages and disadvantages of the *FINESTLUMI* setup. Last but not the least, the first experiments as well as the first results obtained at *FINESTLUMI* will be demonstrated and discussed.

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Development and verification of a new OSL-ring dosimeter system

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For some special radiation practices, such as radiation workers operating radioisotopes in nuclear medicine department, hand exposure is inevitable and is usually obtained higher radiation doses. Therefore, wearing the ring dosimeter on the finger to monitor the hand (extremity) dose is frequently used. Most current commercial ring dosimeters are typically in TLD type and consist of single dosimetry chip, and do not have the ability to distinguish the energies of irradiated radiation. This study developed a new OSL-ring dosimetry system containing OSL-ring dosimeters and an OSL reader. Each OSL-ring dosimeter consist of two OSL dosimetry chips. The dimension of OSL-ring dosimeter is 1cm in diameter and 0.4 cm in thickness. The dose algorithm was also designed to calculate the dose considering the correction of energy dependence. The new OSL-ring dosimeter system was verified by means of the irradiated test using X ray, gamma ray beams and beta sources in the National Radiation Standard Laboratory of Institute of Nuclear Energy Research (INER) in Taiwan. The tested results of the new OSL-ring dosimeter system are presented in this paper. In conclusion, due to the TLD can't be read repeatedly, the new developed OSL-ring dosimeter system with ability of repeated reading has more confidence and reliability compared to the traditional TLD rings with single dosimetry chip.

Hierarchical clustering of CsI(Tl) scintillation detector pulses

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Traditionally, all the photons generated during the scintillation process are considered to be "identical" and their contribution to the formation of the amplitude spectrum is not differentiated. Last results show that "fast" and "slow" pulse components, arising apparently from various processes possess with different statistics. Let us hypothesize that the photons generated by different processes are not statistically identical. In such case, the decomposition of the multitude of pulses measured at the output of the photomultiplier based on the domination of a certain type photons in them will make it possible to differentiate the contribution of various scintillation mechanisms.

A series of scintillation and numerical experiments were carried out. A set of approximately 500 thousand pulses (18 microseconds long) were vectorized. Under vectorization one can see the counting of a certain number of partial sums (integrals) of each pulse and the formation of these sums to vectors for each pulse in the set. The amplitude spectra for these sets were plotted. The clusterization of the obtained vectors that have fallen into one channel of the amplitude spectrum was carried out. In all experiments, the multitude of pulses in each channel was divided into 3-5 groups of which 1 or 2 in terms of the number of elements exceeded significantly the others.

An extra series of experiments is aimed to the study of the pulses shape without differentiating them by amplitude spectrum channel. The essence of the experiment consists in calculating the distance matrix according to Euclidean, correlation and soft cosine norms and carrying out the hierarchical clustering [1] of the whole multitude of pulses in the experiment data. The result is a set of clusters and a dendrogram of clusters (easy visualization of decomposition of pulses to groups). Amplitude spectra plotted basing on the obtained clusters, in most cases, have different width at half height of the maximum absorption pulse.

Finally, it is shown that indirect methods for differentiating photons from various processes at the light output could be applied to scintillator resolution check. Proposed decomposition methods could be helpful both for the study of a scintillation process and for a number of engineering solutions for spectrometric tasks.

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Pulse shape discrimination study with new Tl_2ZrCl_6 crystal scintillator

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The pulse shape discrimination (PSD) possibility of the Tl_2ZrCl_6 crystal was investigated. This crystal was grown from the melt by vertical Bridgman technique. Energy resolution, Light output, decay time, quenching factor and pulse-shape characteristic were investigated at room temperature. This scintillator shows high γ- and X-ray detection efficiency due to its high effective atomic number, high light yield and good energy resolution of 4.3% FWHM at 662keV. Pulse shape discrimination has been studied for signals induced by α-particles and γ-quanta from ^{241}Am and ^{137}Cs sources, respectively. The figure of merits above 511 keV was obtained to be 9.1 and 11.6 for both mean time method and optimal filter method, respectively. It indicates that α-particles from ^{35}Cl (n, α) ^{32}P reaction can be clearly separated from the gamma background. We expect that this scintillator might be a promising candidate for the fast neutron spectroscopy owing to its high Cl concentration and low thermal neutron cross-section. Therefore, it can be used for both fast neutron and gamma-ray spectroscopic applications.

Investigations of halide scintillators at the atomic and micro scale

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This presentation will focus on information obtained by using advanced characterization techniques to further the understanding of scintillation mechanisms and accelerate the crystal process development. Moving forward in the development of scintillators require careful engineering of defects either unintentional (intrinsic) or added (alloying or co-doping) to improve one or more properties of the scintillator. Microscale structures, defects localization and formation are now needed knowledge. Halides present unique challenges for transmission electron microscopy and may have never been imaged at sub-Ångstrom scale. We will present results on the structure of $CsPbBr_3$ imaged by CBED and Electron Ptychography, and present sub-Ångstrom resolution images of a co-doped mixed halide. The power of Energy-Resolved Neutron Imaging as a real-time diagnostic tool will be demonstrated for real-time crystal growth visualization and quantification of elpasolites. The location and shape of the interface between liquid and solid phases are monitored in real-time, concurrently with the measurement of elemental distribution within the growth volume and with the identification of structural features with a 100 μm spatial resolution.

Thermoluminescence governed by the Auger-recombination process

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In the present work, we study the possibility that a thermoluminescence (TL) peak is governed by the effect of Auger recombination, an effect which has been considered for other luminescence phenomena. In Auger recombination in the form of interest here, two conduction-band electrons are involved in the recombination of one of them with a hole in a center. The two electrons collide in the presence of the center, one loses energy and recombines, yielding a TL photon, and the other gains energy and speeds away. As mentioned with regard to other luminescence phenomena, in this case, in the set of differential equations governing this process, a term proportional to the square of the free-electron concentration should be included according to the law of mass action. The relevant set of simultaneous differential equations has been solved numerically for feasible sets of parameters. The results yield a relatively narrow TL peak which is somewhat asymmetric, with the fall-off half being larger than the low-temperature half. Under appropriate conditions, the set of equations is shown to reduce to an approximate third-order kinetic equation, the solution of which has a very similar symmetry. The third-order approximate curve has an effective activation energy which is twice as large as the original. Such asymmetric peaks have been described in the literature. Also, when using standard peak-shape methods for evaluating the effective activation energy and frequency factor, very high values of these magnitudes have been found due to the narrowness of the simulated peak. This model may explain the occurrence of such TL peaks previously reported in the literature. A similar explanation may be useful in explaining anomalous fading of TL, which may be an alternative to the presently acceptable interpretations. In another version of the model, an additional thermally disconnected trap is considered. With certain sets of parameters, the simulations yield a cubic dependence of TL intensity on the excitation dose, an effect previously reported in some materials.

β-Ga_2O_3:Ce as a Fast Scintillator: a Doubtful Role of Cerium

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In the continuous quest for new fast scintillators, semiconductor materials attract more and more attention [1], with β-Ga_2O_3 being one of the most promising candidates [2-5]. Although this compound itself is capable of producing very fast and moderately efficient scintillation, perspectives for a further enhancement can be discerned in intentional introducing of some activator elements. Cerium ions, already recognized as a prominent activator for diverse inorganic solid-state scintillators [6], could be particularly tempting, the more that the 4.85 eV bandgap of β-Ga_2O_3 seems to be wide enough to let the Ce^{3+} $5d$-$4f$ luminescence appear.
In this Communication we present the results of pulse height, radioluminescence and scintillation time profile measurements performed on β-Ga_2O_3 and β-Ga_2O_3:Ce crystals grown by the Czochralski method at LICG [7]. We show that it is the free carrier concentration that mostly influences the scintillation light yield. The effect of cerium activation on the yield, if any, is rather small. Similarly, the X-ray excited emission spectra look the same regardless of the presence of cerium. Interestingly, the scintillation decay time constants of β-Ga_2O_3:Ce are prolonged compared to those of β-Ga_2O_3. Although all these observation call into question the point of adding cerium to β-Ga_2O_3, we trust that it is not the last word on the matter, hence we discuss the reasons of the current situation and search for ways of its improvement.

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Normal and anomalous luminescence in SrS:0.05 %Ce^{3+} under high hydrostatic pressure

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Luminescent properties of SrS:Ce pellets sintered at 1700 °C were investigated under high pressure. Two different Ce^{3+}-related emissions were confirmed to appear in blue-green (N band) and red part (A band) of spectrum and were shown to shift significantly and linearly to longer wavelengths with increasing pressure. Changes in decay times of both emissions were also thoroughly analyzed.

The photoluminescence and photoluminescence excitation measurements confirmed that N and A bands are related to Ce^{3+}emission from two different crystallographic sites. Both emissions - the normal in blue-green and the new one in red range - shifts significantly toward lower energies with pressure becoming simultaneously distorted. Pressure rate of the emission shift exhibits similar magnitude for both of them. Time resolved luminescence revealed quite long decay for both the Ce^{3+} emissions but definitely longer for A-band. The lifetimes of the N-band and A-band depend on pressure. The persistency of the latter is especially well seen in decay profiles measured under high hydrostatic pressure under 520 nm excitation appearing in longer component with time 77 ns for 60 kbar. Above this pressure the gradual diminishing of the A-band luminescence decay was found related to decrease of the energy barrier for nonradiative depopulation of the lowest 5d state. The origin of red Ce^{3+} we related to generation of the ${Ce_{Sr}}^{+}$ + ${V_{Sr}}^{-}$ spatially correlated defect system/center as a result of a short distance compensation of the positive net charge of Ce^{3+} ions replacing Sr^{2+} in SrS crystal lattice. The most probably specified energetic structure of the center increases the probability of electron tunnelling from the $5d^1$ level of Ce^{3+} to the center manifesting in shorter component in A-band luminescence decay. Simultaneously the + is responsible for creation of the Ce ion in the Ce^{4+} . We have shown that ${Ce_{Sr}}^{+}$ + ${V_{Sr}}^{-}$ is the excited state of the ${Ce_{Sr}}^{++}$ + ${V_{Sr}}^{--}$ system and this state can be metastable . Accordingly, back-transfer from to the Ce^{3+} $5d^1$excited state could be involved in generation of the slower component in the decay and persistence luminescence observation under 520 nm excitation.

Growth and scintillation properties of Ce^{3+}-doped thin film garnet and perovskite scintillators

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We focus in this contribution on oxide scintillator films, primarily on garnets and perovskites doped with Ce^{3+} ions, prepared by liquid phase epitaxy. Particular attention will be paid to multicomponent garnets GAGG:Ce and perovskites YAP:Ce. The scintillation properties of garnet system are considerably improved by intentional co-doping by divalent Mg^{2+} or Ca^{2+} ions [1]. Excellent timing properties of these co-doped garnets make them competitive candidates for high rate imaging techniques and other applications. Markedly shorter decay time of 18 and 8 ns, respectively, is observed in Ce and Pr -doped perovskites. The decay time of this material can further be reduced by suitable co-doping and by modifications of technology process. This feature, along with generally low afterglow, makes perovskite scintillators attractive materials for ultra-fast applications.

The scintillation properties of epitaxial garnet and perovskite films will be reviewed and discussed. Reversible changes of cerium ion valency by suitable co-doping and thermal treatment is demonstrated. The effect of reversible changes of cerium valency by suitable co-doping and thermal treatment on the scintillation properties will be demonstrated.

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Effects of nonstoichiometric composition on luminescence and scintillation properties of Ce doped $Gd_3Al_2Ga_3O_{12}$ single crystals

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Inorganic scintillators which convert high energy ionizing radiation to thousands of UV-visible photons, have been playing a major role in many fields of radiation detection, including medical imaging, security, astrophysics, particle physics, and well-logging. Rare earth activated wide band gap oxide crystals have been found very useful as such detectors. A number of crystals activated by Ce^{3+} ions have been studied as potential fast and efficient scintillators. The cerium doped multicomponent Gadolinium Aluminum Gallium Garnet (Ce:GAGG) is one of the recently developed scintillator material [1]. Our group reported that Ce:GAGG offers excellent scintillation properties of high light yield (46,000-56,000 photons/MeV) and fast decay time (92 ns) [2,3].

Although these Ce:GAGG crystals have attracted much attention with their outstanding scintillation properties, there seems to be some room for improvement. It was recently proposed that the scintillation properties of Ce:GAGG could be improved by changing the stoichiometric ratio between Al and Ga [3].

In this study, we investigated the improvement of scintillation properties with Ce:CAGG crystals having nonstoichiometric composition of Gd or Al or Ga. The 0.5% Ce doped GAGG single crystals were prepared by micro-pulling down (m-PD) method with a stoichiometric composition as a standard and with a ±5mol% of Gd/Al/Ga.

Absorption, radioluminescence, PLE and PL spectra were measured together with several other scintillation characteristics, namely the scintillation decay and light yield to reveal the effect of composition change. Details of compositional analysis and changes in scintillation properties with compositions will be reported in my presentation.

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Fluorescent nuclear track detectors (FNTDs) to model RBE in proton therapy: correlation to microdosimetric quantities and biological observations

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Nowadays clinical proton therapy (PT) facilities still use a constant relative biological effectiveness (RBE) value of 1.1 while several studies showed an increase in RBE associated to an increase in the linear energy transfer (LET) of the proton beam towards the distal part of the spread out Bragg peak (SOBP). Nevertheless, no gold standard yet exists for experimental evaluation of individual proton tracks and validation of available measurement devices and simulations are lacking. In the current study confocal microscopy data from Fluorescent Nuclear Track Detectors (FNTDs) are compared to microdosimetric quantities and correlated to biological observations in different positions of the SOBP, with a special emphasis on the distal fall-off region. A Perspex phantom was irradiated at NRF iThemba LABS with a scattered 198.5 MeV proton beam (12 cm range, 5 cm modulation, 10 cm diameter field size). RBE values were obtained by performing a colony survival assay (CSA) with Chinese hamster ovary (CHO-K1) cells at 6 different positions (entrance plateau, SOBP, ±80% D_{max}, ±60% D_{max}, ±40% D_{max}, ±20% D_{max}). In the same locations, dosimetry was performed with the MicroPlus Probe, FNTDs and simulations (GEANT4). LET spectra as well as track and dose averaged LET in water, $LET_f$and LET_d, were derived using an empirical relation between track intensity and LET, generated from FNTD irradiations in mono-energetic ion beams.

The FNTD microscopic images clearly show a decrease in the particle fluence with depth while the track intensities increase with LET_f values up to 6.7±2.0 keV/μm, 8.4±2.7 keV/μm and 5.9 ± 1.7 keV/μm at 60% D_{max} , 40% D_{max} and 20% D_{max} respectively. The uncertainties can be mainly attributed to the calibration performed through empirical exponential fitting (±28%). A good agreement was observed between LET_d and the microscopic quantity, y_d, certainly in the distal part of the SOBP. Moreover FNTDs allow to generate LET spectra which show a broadening of the frequency spectrum with depth and at the distal edge 2 peaks can be distinguished; one centered on 0.9 keV/μm and another one on 6 keV/μm. Finally the increasing LET_d with depth was correlated to an elevated RBE reaching up to a value of 1.47±0.08 at 20% D_{max}. Although more extensive research is needed to further improve accuracy of the LET quantification, FNTDs are small passive detectors offering a flexible approach that can be very interesting in experimental studies of biologically relevant microdosimetric quantities.

Experimental Alpha Particle Microdosimetry using Fluorescent Nuclear Track Detectors

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The interest in alpha radionuclide therapy remains on the rise, partly for its ability to deal with radioresistance (micro)tumours attributed to the high LET of alpha particles. The dosimetry of alpha particle emitters is challenging because of the stochastic nature of energy deposited in small, subcellular targets. We present a novel, experimental method employing Al_2O_3:C, Mg Fluorescent Nuclear Track Detectors (FNTD), which offer submicron measurement of alpha particles, yielding their initial location, direction and energy with good accuracy. The detailed information of the radiation field was used together with 3D images of U87 cells stained for cytoplasm and nucleus to the derive the specific energy distribution of cell nuclei irradiated with an external ^{241}Am source. The distributions based on the FNTD approach matched closely with the outcome based on a analytical model. For U87 cells irradiated with the ^{241}Am source, the survival slope based on the absorbed dose was experimentally determined at α_D = 1.66 ± 0.14 Gy^{-1}.Using the new method, the microdosimetric survival slope yielded α_z = 1.92 ± 0.19 Gy^{-1}. The presented method avoids the need for complex Monte Carlo simulation and assumptions regarding the radiation field and cell geometry and is therefore far less susceptible to bias and easier to apply. The presented method can be of great value for DNA damage en repair studies and alpha radiation therapy reserach in general.

LM-OSL investigations of X-rays irradiation on terracotta

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Optically stimulated luminescence (OSL) is used, as well as thermoluminescence (TL), in our laboratory to investigate the authenticity of ceramic art objects from museum collections. Such objects could have absorbed, during their life, dose from artificial source, mainly X rays used for radiography. In the framework of a study of the X-rays effects, we have investigated the X-rays induced defects using the linear modulated - OSL (LM-OSL) technique in order to identify X-ray induced defects from defects induced by alpha and beta particles. The regular increase of the stimulation power permits to monitored the various traps in the crystal. The advantage of the LM-OSL is to work with low heat (125°C) reducing the risk of thermal perturbation of the crystal encountered with TL.

Clinical Application of Ionization Density Dependence of the Glow Curve Characteristics for Linear Energy Transfer (LET) Measurements in Therapeutic Proton Beams

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Linear energy transfer (LET) is related to the relative biological effect caused from the particle therapy. The LET is a candidate parameter for optimizing proton therapy treatment plan as considering biological effects. Therefore, being able to measure LET in clinical sites becomes significant. This study is to develop a LET measurement system using the ionization density dependence of the glow curve characteristics of thermoluminescent dosimeters (TLD), LiF:Mg,Ti, in clinical therapeutic proton. Hence, TLDs can be not only dosimeters but also LET detectors.

The ionization-density dependence of the glow curve is appeared in the high temperature region. The ratio of the integral TL intensities at the specified high-temperature region induced by a proton beam and a photon beam is denoted as the high temperature ratio (HTR). The relationship between HTR and LET was determined. The TLDs were irradiated with the same dose at several depths of a HDPE phantom using three types of radiation: a ^{60}Co γ source at the National Measurement Laboratory of the Institute of Nuclear Energy Research, a 6-MV photon beam (Truebeam, Varian), and a 190-MeV proton beam (Sumitomo Heavy Industry, Japan) at the Chang Gung Memorial Hospital. The LETs varied with proton energy at different phantom-depths were simulated with TOPAS (version 3.0.1). The HTRs were around 0.873 to 1.40 for the proton/^{60}Co combination, and 0.319 to 0.511 for the proton/6-MV x-ray combination, respectively. The LET for 190-MeV proton ranges from 0.5 to 7 keV/ μm. The LET measurement system could be developed using comparing TL intensities casued by proton beams with those by both ^{60}Co γ rays or 6MV photons. It is more convenient to build the system with Liniac photons for most medical facilities.

Are there dose-rate effects in the thermoluminiscence of LiF:Mg,Ti (HARSHAW)?

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The literature describing the experimental investigations of possible dose-rate effects in the thermoluminescence (TL) of LiF:Mg,Ti (Harshaw) has been recently reviewed [1]. The total lack of glow curve analysis, coupled with inclusion of all or part of the high temperature TL and lack of parallel measurements of possible dose-rate effects in the irradiation stage monitored by optical absorption severely limit the scientific and technical level of the experiments. In addition, the description of the details of the experimental procedures and adopted protocols are far from sufficient to warrant any decision concerning the presence or absence of dose-rate effects in the TL of LiF:Mg,Ti. This is contrary to the common belief that there are no dose-rate effects in the TL of LiF:Mg,Ti. In addition, the literature on dose- rate effects in the optical absorption (OA) of LiF are reviewed and are found contradictory. No dose-rate studies have been carried out on OA in LiF:Mg,Ti. Theoretical considerations suggest the possibility, even likelihood, of dose-rate effects mainly due to competition between excitation and recombination in the irradiation stage [2] as well as other possible mechanisms involving multiple charge carrier trapping. For example, the V_3 center, a two-hole center, must be populated simultaneously by 2 hole capture since "1-hole" capture resulting in the V_k center is unstable at room temperature. Its rate of population is expected to be dose-rate dependent, and during the irradiation stage it competes for holes which might otherwise reach the TL luminescent centers. Kinetic simulations support this hypothesis. Preliminary experiments at the Soreq Nuclear Research Center in which TLD-100 samples are gamma- irradiated to 1 Gy but at different dose rates (and duration of irradiation) by changes in the source-sample distances do not seem to follow the r^{-2} law at distances close to the source thereby implying the possible presence of dose-rate effects. Other possibilities/hidden variables also require further investigation. Other experiments in different irradiation facilities are underway.

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Statistical-based modeling and nanoDot OSL dosimetry for evaluation of potential factors contributing to radiation-induced skin injury during Transarterial Chemoembolization

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Throughout the years, liver cancer and Cholangiocarcinom have been observed as the leading cause of death in Thailand, especially in Khon Kaen and the northeast region where have been recorded the highest incidence rate of liver cancer in the world [1]. The main source of high prevalence in this region is related to the habit of eating uncooked cyprinoid fish infected with liver fluke (Opisthorchisviverrini: OV) [2]. Although, various techniques have been introduced in order to achieve successful treatments, all of them have both advantages and disadvantages concerning the evidence-based diseases and conditions. Transarterial Chemoembolization (TACE) has been accepted as an effective technique commonly to be used in hospitals, however radiation-induced skin injuries caused by excessive high doses to patients during fluoroscopically guided procedures are significantly concerned. The purposes of this study are to: 1) quantify the risk in radiation-induced skin injuries to patients undergoing TACE treatments at Khon Kaen University Hospital; 2) evaluate the potential factors contributing to the increase in patient's entrance skin dose (ESD); and 3) demonstrate an improved image-guided procedure for reduction of patient's entrance skin dose without destroying diagnostic image quality. ESDs obtained from 370 patients were observed under three specific techniques routinely used for patient treatments at Khon Kaen University Hospital including: 1) Abdomen frontal technique where the pathway of blood flow was created using fluoroscopy rate of 3 frame/second; 2) Navigation technique where blood vessel roadmap was created with subtraction of bones and organs; and 3) Fluoroscopy technique where x-ray beams were continuously shot to provide real-time imaging. Using analysis of variance (ANOVA), no significant differences of the mean values among the three techniques were observed. Statistical-based modeling using multiple regression analysis and nanoDot OSL dosimetry were used to predict ESDs and evaluate all potential factors. Energy of x-ray beams (kV), intensity (mAs), fluoroscopic treatment time and thickness of patients were found as four main factors contributed to the patient's ESDs.

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Thermoluminescence of AMOLED substrate glasses in recent mobile phones for retrospective dosimetry

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Emergency dosimetry using thermoluminescence of display glasses in mobile phones was proven its possibility with favorable dosimetric properties [1]. Compared to decreasing electronic components like resistors and inductors in a mobile phone, the display glass has higher availability with a trend of increasing size. In particular, the availability has a major advantage over situations such as measurement errors, sample loss and light exposure prior to OSL measurement for a limited number of samples. Most of the previous studies have been carried out using substrate glasses in liquid crystal display (LCD) in relatively old mobile phones. In recent years, mobile phones with an active-matrix organic light-emitting diode (AMOLED) display have been increasing enormously, and therefore it is necessary to verify the possibility of AMOLED glasses as an emergency dosimeter. In this study, 40 recent mobile phones using AMOLED glass were analyzed and the models vary from Samsung Galaxy-S3, S5, S6, note-4, etc. The target material was the substrate glass for AMOLED layers which is enveloped under the touch glasses. TL emission spectra and glow curves showed that the ratio of category A and B glass according to glow curve shape of the previous study [1] was about 80% and 20% for all measured samples, respectively. Higher signal from whole wavelength region of the PMT were recorded by removing the blue filter and the pre-bleach protocol was applied. This was possible in a single measurement sequence by modifying the Risoe TL/OSL DA-20 reader which separates the LED module for pre-bleach from the detector unit. The zero dose distribution with an average of 50 mGy and a maximum of 500 mGy was recorded for all samples. The zero dose distribution according to the position of the glass was also obtained for the sample with the highest value. In addition, the variation of zero dose and minimal detectable dose (MDD) according to the signal integration window in a glow curve was confirmed. Statistical fading data were obtained by measuring all samples up to 40 days from the irradiation. Linear dose responses ranging from 100 mGy to 10 Gy and a low sensitivity change over 10 repeat measurements were observed.

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Dose conversion from a material dose to whole body dose using mesh phantom for retrospective accident dosimetry

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As one of methods for the retrospective dosimetry, thermoluminescence (TL) and optically stimulated luminescence (OSL) measurement of materials in a mobile phone has been introduced. The method is more suitable for emergency dosimetry right after an accident and can be carried out non-invasively for numerous people in a short time than other techniques. Since, however, the estimated dose using the TL/OSL originated from a mobile phone is not a human body dose, several studies were performed to convert the dose to the human body dose. Because it is hard to derive the conversion coefficients for whole body dose with experimental method, it should be obtained through simulation with considering various situations and factors. In previous study, MCNP simulation was carried out using resistors of a mobile phone on a voxel phantom model of the International Commission on Radiological Protection (ICRP) reference male (ICRP 2008). However, when the simulation with the voxel phantom is performed, some anatomical errors could be followed. First, the skin of voxel phantom has many holes incurring significant error in dose estimation for charged particles due to cuboid-shaped voxels. Second, the size of voxel unit which has about 2 mm for standard ICRP phantom is hard to render small tissues. Third, the voxel phantoms are not flexible to modify postures like squatting, sitting and bending. In recent years mesh phantoms have been developed, and these make possible to solve the problems like occurring the holes, limited thickness and posture. In the present study, the simulations were performed to obtain the conversion coefficients using the mesh phantom. The geometry of the mobile phone was modeled by reflecting the structure of latest mobile phones. The display glass was selected as a target material since it has higher availability than resistors which are decreasing in recent mobile phone. Three different positions (chest pocket, hip pocket, thigh pocket) of a mobile phone on the phantom were considered because a mobile phone owned by individual can be located in various positions. In addition, various exposure conditions and postures were considered: anterior-posterior (AP), posterior-anterior (PA), left-lateral (LLAT) and right-lateral (RLAT) with four different postures (standing, squatting, sitting and bending). The simulations were performed with Geant4 simulation code. Consequently, the conversion coefficients will be provided as a lookup table to convert a material absorbed dose to whole body dose in a short time.

On the use of display touch glass of mobile phone as a fortuitous dosimeter in radiation accident

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The dose reconstruction using thermoluminescence and optically stimulated luminescence (TL/OSL) from personal items enabled fast triage in accident dosimetry. In recent years, the method using TL from a display glass of mobile phone has been intensely studied, but most of materials used were limited to a bottom substrate glass due to low zero dose signal [1,2,3]. However, the substrate glass from recently released mobile phones is not easy to handle due to its fragile thickness. Relatively thick touch glasses are known to have a limitation result from higher zero doses, but recent studies have attempted to reduce the zero dose through mechanical etching because zero doses are supposed to be induced by UV illuminations [4]. In the present study, dosimetric properties of the touch glasses have been studied with chemical etching method. The effect of chemical etching of the glass with hydrofluoric acid on the zero dose signal was tested with increasing the treatment time by 30 seconds. The TL emission spectra for each glass were acquired to categorize the glasses which are different from the categories in previous study [1]. More than 4 different spectra with a peak at 310 ^{o}C / 560 nm, 270 ^{o}C / 670 nm, 320 ^{o}C / 470 nm and 250 ^{o}C / 380 nm were classified for touch glasses. Zero dose distribution of each glass was recorded for over 30 models of recent mobile phones. A long term stability of signal was also acquired up to 40 days from the time of irradiation. A dose response from 100 mGy to 10 Gy and a sensitivity change over 10 repeat measurements were measured.

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Extending the measurement temperature range in a fully automated luminescence reader to -50 °C

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The temperature dependence of luminescence phenomena above room temperature is well-known. For lower temperatures knowledge is rather limited, as more detailed studies have been hampered by the lack of luminescence readers that allow cooling as well as heating in a fully automated setup. Here, we present a Lexsyg Research luminescence reader [1] equipped with cooling unit to irradiate and measure samples below ambient temperature. Within the measurement chamber of the Lexsyg reader the transport arm that moves aliquots between irradiation and readout position was redesigned and the standard heating element mounted on one side of the arm was complemented with a Peltier element on the opposite side.

The thermoelectric cooling device allows cooling and heating a sample over the temperature range -50 °C to 100 °C. For heating beyond 100 °C the sample is transported to the standard heating element of the reader. First performance tests of the newly developed cooling unit were conducted and reproducibility tested for different cooling and heating rates as well as different holding time and durations at low temperatures. The maximum holding time for temperatures above -40 °C is longer than 1 h; for temperatures below -45 °C the holding time is limited due the cooling efficiency of the Peltier element and the limited heat transfer.

The temperature control of the element generally is excellent but depends on the cooling and heating rates. For a rate between 0.1 °C/s and 2 °C/s the absolute offset varies between 0.1±0.1 °C and 3.5±1.3 °C during cooling and between 0.4±0.1 °C and 2.4±1.0 °C during heating. When temperature is kept constant during holding periods the cooling unit shows less than 0.1 °C variability. Material used for initial testing were: mineral grains of quartz and feldspar typically used for routine protocols for age determination as well as dosimeter materials (such as BeO; LiF:Mg,Cu,Si; Al_2O_3:C and lime-aluminosilicate glass).

To investigate luminescence efficiency radioluminescence (RL) measurements were carried out at different sample temperatures. Preliminary results of the influence of the low ambient and elevated temperatures on RL, TL and OSL measurements will be presented.

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Ion Spectroscopy using Fluorescent Nuclear Track Detectors and STED Nanoscopy

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Fluorescent nuclear track detectors (FNTDs) made from Al_2O_3:C,Mg single crystals can visualize tracks of swift ions passing through the detector by confocal microscopy. An even higher lateral resolution of FNTD imaging was achieved with a STED nanoscope [1] and other superresolution methods [2]. However, the application of STED to FNTDs exhibits a number of challenges related to crystal properties such as birefringence or the sequential multi-photon absorption processes. The STED nanoscope was therefore further optimized for the specific readout of FNTDs and applied to samples irradiated with wider range of conditions than in [1], namely monoenergetic proton, helium, and carbon beams with LETs from 1.4 to 92 keV/um (in alumina). Additionally, high-LET carbon ions were used as reference radiation with each detector to compensate for sensitivity fluctuation. As a result, the assessment of the dependence of average track width on LET and ion charge could be considerably improved.

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The different reading trays affect the radiophotoluminescence signal in self-made glass dosimeter reading system

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This study investigates the impact of different reading trays on the self-made glass dosimeter reading system. The radiophotoluminescence glass dosimeter (RPLGD) has a diameter of 1.5mm and a length of 1.8mm. The glass dosimeter has been irradiation with 1 Gy. In this study, different measurement reading trays were designed, and the RPLGD signals were taken by charge-coupled devices (CCDs). This study also investigates the stability of self-made reading system. The experimental results show that different reading trays have different readings. The CV values of the reproducibility test in self-made reading system were less than 0.6%, indicating that the self-made system is stable. However, the signal CV is 5% among different trays. Therefore, different measurement reading trays will affect the reading value of the in self-made glass dosimeter reading system.

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Non-proportionality of La-GPS(Ce) in high temperatures

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Non-proportionality and energy resolution function of Ce-doped lantanium-gadolinium pyrosilicate $(La,Ce,Gd)_2Si_2O_7$ (Ce:La-GPS) single crystals, grown by Czochralski method, in high temperatures, is presented. La-GPS:Ce demonstrates high light yield and good energy resolution in temperatures up to 150 deg C. The measurements of 10x10x5 mm^3 samples coupled to temperature-resistant ET Enterprises 9110V02 photomultiplier in a climate chamber, giving the temperatures up to 180 deg C are presented. Custom designed, temperature resistant gamma-ray calibration sources, made by Polatom Radioisotope Center were used to obtain the non-proportionality curve in a wide energy range. The temperature effect on intrinsic resolution of the crystals is studied.

[1]

[2]

Calculation of Detection Efficiency of Large Volume Source Using EXVol Code

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To calculate the full energy (FE) absorption peak efficiency for arbitrary volume sample, we developed and verified the EXVol (Efficiency calculator for eXtended Voluminous source) code which is based on effective solid angle method [1]. The procedure for semi-empirical determination of the FEP efficiency for the arbitrary volume sources and the calculation principles about EXVol code were validated with HPGe detectors in previous study [2].
Correction techniques for factors that interfere with gamma ray spectrum analysis are required for reliable nuclear characterization and radioactivity determination. And in the measurement of voluminous source of various forms and media, it is necessary to calibrate the effects of the self-attenuation and coincidence summing of the gamma ray depending on the volume and density of the sample. In order to calculate coincidence correction factor, it is necessary to find the detection efficiency at the specfic position
In this study, the performance of the EXVol code was extended to obtain the detection efficiency distribution at a specific position in a large volume source.

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Novel instrumentation for time-resolved luminescence experiments under VUV excitation at PETRA synchrotron

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The works on the new P66 beamline started 5 years ago as a part of PETRA III extension project [1]. The main goal of the P66 beamline assembly is relocation of the very successful experimental station for time- and spectrally resolved luminescence investigations from DORIS to the PETRA synchrotron source. The efficiency of the P66 station is expected to be the same as that of the previous unique station SUPERLUMI [2], which operated in the UV- VUV spectral region with pulsed synchrotron excitation in nanosecond range. Comparable time modes (up to 192 ns) on one hand as well as the increasing number of users with continuous interest in carrying out experiments and high number of publication on the other hand outlined a strong motivation for the future of the P66 at PETRA synchrotron ring. The final layout of the P66, the parameters calculated for the optical elements and timelines for construction site will be presented . Major changes of the beamline setup and electronics upgrade should make experiments more convenient and efficient for more than 20 scientific groups from all over the world.

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The Radiation Characteristics of the Novel Transmission Type X-ray Tube

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The transmission type X-ray tubes have a higher proportion of K-characteristic radiation in the energy spectrum than conventional reflective X-ray tubes. This study investigates the radiation characteristics of the transmission type X-ray tube. In this study, TLD-100H and XR-QA2 radiochromic films were used in the PMMA self-made prostheses to perform dose measurement of reflective and transmission X-ray tubes. Dosimeter measurements were verified using the PTW 31010 ion chamber and EGS4 Monte Carlo simulation. Due to beam hardening caused by different depths of the prosthesis, the X-ray energy spectrum is changed. In the percent depth dose measurement, the variation of the TLD-100H compared to the ion chamber measurement is 4.0% - 13.0%. After modifying the energy dependence of TLD-100H with Monte Carlo results, the variation is less than 2.0%. Within 90.00% of the dose range in dose profile measurements, the variation among XR-QA2, TLD-100H, and PTW 31010 were less than 3.00%; In the same parameters, the radiation output of transmission type X-ray tubes was 13.6 times higher than that of the reflective X-ray tube. Therefore, the transmission type X-ray tubes have better radiation output efficiency.

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Large size LuAG:Pr response to intrinsic radioactivity and external gamma-rays

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Praseodymium doped LuAG is a fast, bright scintillation material characterized with nearly proportional response to gamma-rays that results in good energy resolution of about 5% at 662 keV [1], [2]. Its high density of 6.7 g/cm^3 and effective atomic number of 59 make it a good candidate for gamma-ray spectroscopy detector. However presence of Lu-176 in crystal lattice is a source of internal radioactivity. Lu-176 decays via β^- decay with emission of a cascade of 3 gamma quanta with total energy of 597 keV. Self-absorbed decay products give rise to internal background spectrum with yield of about 200 cps per cubic centimeter [3].

Efficient gamma-ray detection requires use of large volume samples. Since we have in our laboratory a 2 inch diameter and 3 inch height LuAG:Pr crystal from Furukawa Co., Japan, we decided to test it as a gamma-ray detector. Presence of Lu-176 in such a large LuAG sample results in about 3×10^4 cps of internal radioactivity background counts. Within the course of this study we plan to perform coincidence measurements between a large size LuAG:Pr and a good energy resolution reference detector, gating the spectra on gamma-rays that escape the LuAG:Pr sample. The goal of this research is to measure the response of LuAG:Pr to intrinsic radioactivity from β^- decay of Lu-176. An attempt to record gamma-rays response of LuAG:Pr with reduced intrinsic background by using a reference detector in a VETO mode will also be made.

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Investigations on luminescence properties of 3 mol % ERBIUM-doped phoshate glass produced at JUIZ DE FORA FEDERAL UNIVERSITY

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In the past few years, phosphate-based glasses belonging to promising laser glass hosts were extensively studied and their crystallographic structure and optical properties were characterized using different spectroscopic techniques. Recently, glasses doped with rare-earth ions have attracted much attention due to their potential applications in solid-state lasers, optical amplifiers and three-dimensional displays. For years much attention has been attracted to the research of the rare earth (RE) ions. Among them, erbium is the most interesting and a lot of work has been done on the spectroscopic properties of Er^{3+} doped phosphate glasses. However, little to no attention has been given to potential luminescent properties from "heating" the material. The Dosimetric Materials Laboratory of the Instituto de Pesquisas Energéticas e Nucleares - LMD/IPEN has tradition in research related to TL and OSL materials and its applications. Thus, this work aims to present the results on investigations of TL and OSL properties of the Erbium-doped phosphate glasses produced at Federal University of Juiz de Fora for beta radiation dosimetry. The TL and OSL investigations were performed on a TL/OSL-DA-20 model RISOE reader and its coupled ^{90}Sr/^{90}Y source with initial dose rate of 0.1Gy s^{-1}. For the TL investigations, the reader was programed to perform a linear heat up to 450^{o}C with constant heating hate of 5^{o}C s^{-1}. For the OSL investigations it was used continuous-wave (CW-OSL) mode of illumination of the Blue LED array and, 90 % of power and stimulation time of 60 s. The experimental findings of this work indicate that Erbium-doped phosphate glasses produced at Federal University of Juiz de Fora presents thermo (TL) and optically stimulated luminescence (OSL) over the range of absorbed doses of 2 to 20 Gy beta radiation. . Its emitted signal is more intense and with extended linearity range compared with pure phosphate glass. Further investigations are being carried out in order to determine its intrinsic efficiency and responses to other types and qualities of radiation.

Compact TL-OSL reader for YAP:Mn detectors

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Mn-doped $YAlO_3$ (YAP) is known as a high-*Z* material for thermoluminescent (TL) dosimetry of ionizing radiation (see [1] and references therein). In particular, the green emission from Mn^{2+} ions occurring at the main TL peak at 200°C can be used for this purpose. This TL signal fades strongly at daylight (bleaching effect), and optical stimulation by blue-green light can be used for its readout. Coincidence of the emission and stimulation wavelengths as well as photoluminescence of Mn^{2+} ions complicates the continuous OSL readout of the material. However, a possibility of pulsed OSL readout of the material has been demonstrated recently [2].

The present study deals with development of compact and fully functional demonstration model of the time resolved pulsed OSL (TR-OSL) reader for YAP:Mn detectors. The instrument under development utilizes the TR-OSL technique proposed in [2]. Here the blue LED (λ_{max}=470nm, P_{max}=620mW) is used for optical stimulation. Indeed, only small fraction of available output power was used in the present experiments. The OSL output is measured with a Hamamatsu H9305-04 PMT module and dedicated signal processing electronics using the photon counting mode with background compensation. A green bandpass filter (λ_{max}=530nm, 60nm bandwidth) is installed in the emission light path. The estimated dynamic range of the optical signal is at least 5 orders of magnitude. The optimal time parameters (stimulation pulse duration, measuring time gate and number of stimulation pulses) have been chosen experimentally to get the largest signal to noise ratio. The OSL response for each stimulation pulse was recorded separately to facilitate the use of several different methods of subsequent processing and analysis. The residual background of about 20cps was achieved. The OSL response after 100 μGy irradiation from ^{137}Cs has been measured reliably for today. The single crystalline YAP:Mn detectors with TL response to ^{60}Co about 40 relative to TLD-100 were used. Further studies on decreasing of the lowest detectable dose are under way.

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Crystal growth and characterization of $K_2LiCeCl_6$ elpasolite scintillator

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$K_2LiCeCl_6$ single crystals, a novel elpasolite inorganic scintillator, were grown by using the two zones vertical Bridgman technique. Scintillation and luminescence properties are measured under X-ray and γ-ray excitation at room temperature. This crystal is so hygroscopic like other alkali halide scintillators that all the measurements and preparation are performed inside the low humidity glove box in argon atmosphere. The X-ray induced emission spectrum of $K_2LiCeCl_6$ is obtained between 300 nm and 500 nm, having maximum emission peak at 370 nm attributed to the 5d - 4f transition of the Ce^{3+} ion. The scintillation decay time under 662 keV (^{137}Cs) γ-ray excitation shows two exponential decay time components of 90 ns (72.8%) and 584 ns (37.2%). The good luminescence and scintillation response of $K_2LiCeCl_6$ single crystals reveal its availability for radiation detection in various applications.

Scintillation properties of undoped and Eu-doped Ca(Br,I)2 single crystals

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Scintillators play important role in many fields such as high-energy physics, medical imaging, geological exploration and homeland security. Recently, halide scintillators have been focused due to the high light yield and energy resolution originated from the small band-gap. Scintillators play important role in many fields such as high-energy physics, medical imaging, geological exploration and homeland security. Recently, halide scintillators have been focused due to the high light yield and energy resolution originated from the small band-gap. Undope CaI_2 and Eu:CaI_2 showed desity of 3.96 g/cm^3, 51 of effective atomic number Z_{eff}, high light yield over 80,000 photon/MeV and 5 8%@662keV with 550 790ns of scintillation decay time[1]. Emission wavelength of Undope CaI_2 and Eu:CaI_2 were 410 and 470nm, respectively. However, it is difficult to obtain single crystals with high crystal quality and process them because they are highly hygroscopic. In this study, crystal gorowth of $CaBr_xI_{2-x}$ was investigated. Relationship between chemical composition, crystal structure and scintillation properties were studied.

8 mm diameter crystals of undope and Eu doped $CaBr_xI_{2-x}$(x=0.5, 1.0, 1.5) were grown by the BS method. 1mm thick samples were cut and polished from the grown crystals. All of the the Eu doped samples showed Eu^{2+} 4f5d emision peaking at around 450-464 nm. The highest light output among the samples was obtained in Eu 2 mol% doped CaBrI and was 71,000 photon/MeV with 7.9%@662 keV of energy resolution. Details abount the crystal structure analysis and scintillation properties will be showed in my presentation.

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Luminescent properties of Vacuum-Ultra-Violet scintillators with a novel Si-PM

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Some scintillators with a fast decay time of less than 100 ns are used in positron emission tomography (PET) due to good timing resolutions. In addition, much faster scintillators with a decay time of less than 30 ns are candidates of a material in time-of-flight (TOF)-PET. Luminescence peaks in the Vacuum Ultraviolet (VUV) originating from 5d-4f transitions (of Nd^{3+}) have shorter decay times (1-20 ns) than in the visible light region, because decay time is proportional to the cubes of emission wagelegh [1-2]. Therefore, VUV scintillator with the inter-configuration 5d-4f transition can be applied to the PET, TOF-PET and other detectors required goof timing resolution.

Up to now, VUV scinitllators are not high light yieds due to the large band gap compared to conventional scintillators with typcal light yields of 5,000 - 50,000 photons/MeV at 300 - 600 nm. Recently, some high sensitive detecotrs, Silicon Photomultipliers (Si-PMs), have been avalable also in the VUV region.

In this paper, we report a novel alpha and gamma-ray detectors consisting of several VUV scintillators such as Nd:LaF_3, Nd:LuF_3 and the VUV-sensitive Si-PM (S13371-6050CQ-02, Hamamatsu), and we detected photo-absorption peak of 5.5-MeV alpha rays. Moreover, we compared the singnal (sensitivity) among VUV-sensitive photo-multiplire tube (R8778 HPK) and the MPPC, and both detecotrs had similar sensitivities.

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An attempt to identify the recombination mechanism in LiF:Mg,Ti (MTS) detectors from spectrally resolved thermoluminescence measurements using the Z test functions

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LiF:Mg,Ti crystal is one of the most popular thermoluminescence (TL) detectors of ionizing radiation. These crystals are grown in various laboratories. Popular LiF:Mg,Ti detectors are produced also at the Institute of Nuclear Physics in Krakow (Poland) under commercial name MTS. In recent years many papers were devoted to the mechanism of trapping and recombination processes leading to the formation of the main dosimetric peak (peak 5) in this material [1]. Nevertheless, the elemental recombination mechanism is still not well known.

Basic theoretical models predict delocalized [2], localized [3] or semi-localized recombination route [4] for the processes in various solids. The different routes may occur simultaneously during TL readout. Usually, it is difficult to distinguish these mechanisms. Recently, Mandowska [5] suggested the use of spectrally resolved thermoluminescence (SR-TL) and/or other spectrally resolved measurements for the identification of localized and delocalized processes. For this purpose the formalism of Z functions was applied.

This work presents an attempt to identify recombination mechanism in MTS detector using various Z test functions derived numerically from SR-TL measurements. There is strong evidence that recombination mechanism in the vicinity of peak 5 is non-localized and non-delocalized.

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Luminescent characterization, structure and morphology of the perovskite-like layered $SrLa_{4-x}RE_xTi_5O_{17}$ compounds

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The luminescent characteristics in relation with structure and morphology of the five-slab perovskite-like $SrLa_{4-x}RE_xTi_5O_{17}$ (RE = Pr, Nd) compounds belonged to the $A_nB_nO_{3n+2}$ - family were measured and described. The crystal structures of the $SrLa_4Ti_5O_{17}$ are formed by two-dimensional perovskite-like blocks where each of them consists of five slabs of the deformed TiO_6 octahedrons connected by vertices only. The blocks are subsequently alternating along the Y axis and are displaced with respect to one another by a quarter of lattice spacing a toward the X axis. So, the possibility of various arrangements of the RE ions in the $SrLa_{4-x}Ln_xTi_5O_{17}$ crystal lattice exists that could be revealed by luminescent investigation in principle.

Reflection, excitation and luminescence spectra were studied using synchrotron tools and radiation in the energy range 3.5 - 20 eV. Experiments with synchrotron radiation were carried-on at SUPERLUMI station of the DESY synchrotron, Hamburg, Germany. Photoluminescence and excitation spectra were also measured at 4.2, 77 and 300 K when the radiation from the N_2- laser, some other lasers of generated wave lengths 405, 473 and 532 nm, Radiation of the powerful Xenon lamp DKsL-1000 filtered through optical monochromated was also used for photoluminescence excitation. The luminescence was registered using MDR-2 and DFS-12 diffraction spectrometers which cover spectral range from 325 up to 850 nm.

Photoluminescence spectra consist of wide emission bands related with radiation transitions in two types of the TiO_6 octahedra of crystal lattice. Additional narrow lines aroused for the sample containing RE = Pr or Nd. Results of experimental studies allowed us to conclude that mentioned above the sets of compounds could be regarded as perspective transformers of the UV or Blue light into visible light, or the white-light-emitting and storage phosphors. When doped with the rare earth ions Pr^{3+} or Nd $^{3+}$ the samples can be considered as perspective fast-scintillation materials.

Growth and properties of ZnO/Alq$_3$/ZnO quantum structures

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In this work we present the ZnO/Alq3/ZnO quantum heterostructures. Thin multilayer films are deposited on glass substrate using sol-gel spin coating technique and these multilayer films influence on optical and structural properties are investigated. Temperature-dependent studies of optical absorption and photoluminescence in these structures, were used to evaluate the well-width dependence and the composition dependence of the major excitonic properties. The optical spectra of dense excitonic systems are shown to be determined mainly by the interaction process between excitons. The high-density excitonic effects play a main role for the observation of room temperature stimulated emission in the ZnO/Alq3/ZnO structure. The binding energy of exciton is enhanced from the bulk values, as a result of quantum-confinement effects.

ZnO:Ga-core-shells embedded in polystyrene matrix

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Photochemically synthesized ZnO:Ga nanopowder is an efficient scintillator with a big potential for the use in fast-timing applications. From the application point of view, it is convenient to fabricate the scintillators in the form of single crystals or ceramics. While the optically transparent scintillating ceramics have been successfully prepared from ZnO powders and nanoparticles, the ceramization of hexagonal ZnO is rather complicated and the material usually does not achieve sufficient luminescence quality. Therefore, high attention is devoted to the preparation of thin films on substrates or composite materials where scintillating nanopowders and nanoparticles are incorporated into the optically transparent matrix. Such composite materials are easier to prepare compared to single crystals or optical ceramics. Aside from bulk composites, core-shell systems form a specific group of composites and follow a specific target - chemical stabilization, surface defects healing or targeting on living cells in the case of biomedical applications.

Polystyrene was chosen as one of the most perspective matrix, due to its optical properties. The amount of 0.5 and 5 g of ZnO:Ga powder was mixed with 50 g of granulate of polystyrene in Brabender lab mixer. The mixture was then press compacted in stainless steel frame, which was placed between the pairs of glass and stainless steel slabs, into the 1mm thick plate. Subsequently, a pellet of 25 mm diameter was cut from the plate. Covering ZnO:Ga heat-treated particles with amorphous SiO_2 layer via sol-gel process improves the RL intensity due to the passivation of the surface. Highly luminescent nanocomposite of ZnO:Ga powder embedded in the polystyrene scintillating host matrix was successfully prepared and composites with the 10 wt% fraction of ZnO:Ga feature very good timing performance. The most important fact is that the composite retains desirable properties of ZnO:Ga, i.e. its intense exciton-related luminescence in the UV spectral range and sub-nanosecond PL and RL decays. The dominance of ultrafast component even under the band-to-band excitation into the polystyrene host or picosecond X-ray pulse excitation shows that there is fast and effective non-radiative energy transfer from polystyrene host towards ZnO:Ga scintillating powder.

Synthesis and TL and OSL characterization of MgB_2O_4-MgB_4O_7 glasses for dosimetry

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In this work we aim to investigate some structural and dosimetric properties of new MgB_2O_4-MgB_4O_7 borate glasses with different structural combinations, doped with 0.5% and 1.0% by weight of Ce_3+ and Li. These glasses were produced by fusion method and rapid cooling. The compounds used are from Sigma Aldrich with a purity of 99.99%. The dosimetric characterization was performed using thermoluminescent (TL) and optically stimulated luminescence (OSL) techniques. Characteristics such as linearity, reproducibility and fading were evaluated after samples had been irradiated with beta source (^{90}Sr+^{90}Y). X-ray diffraction analyses confirmed that no crystalline phases were formed after heat treatment. The doped borates glasses presented high TL and OSL sensitivity, indicating a possible application for dosimetry. Although the fading of the TL and OSL signals are intense in the first few hours after irradiation, the signals tend to stabilize allowing evaluation of absorbed doses after days.

Dosimetric coatings on aluminium surface

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Plasma electrolytic oxidation (PEO) is an electrochemical method of producing oxide coatings on metal surfaces. With already available wide range of technological applications due to their outstanding mechanical properties, during recent years PEO coatings are emerging as novel optical material field. [2] In this study, for the first time intense thermostimulated luminescence (TSL) was observed from PEO coatings.

Al6082 aluminium alloy was used as a substrate. Desired dosimetric effect was achieved by modifying the electrolyte as well as adjusting electrical parameters. One wide thermoluminescent glow maximum is observed peaking at 430K. Spectral distribution during thermostimulated luminescence measurements consists of 2 main bands - green band at 530nm with FWHM≈60nm and asymmetric red band at 710nm (possibly due to many dopants from Al6082 itself or residuals). The optimization of various parameters (first stage) was performed, crystalline structure was defined using XRD and additional experiments were performed.Luminescence characteristics were found to be comparable to the existing dosimeters (TLD-500). Some of the potential practical applications are demonstrated.

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Phototransfer effects and optically stimulated luminescence in strongly irradiated anion-defective corundum crystals

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It was found in [1] that the upper limit of doses registered by TLD-500 detectors based on anion-deficient corundum (α-Al_2O_{3-d}) is 30-300 Gy. Nevertheless, it was noted in [1] that the response and kinetics of the OSL decay curves depend on the degree of the deep traps filling, emptying in the temperature region above 500 K. Thus, with an increase in the preliminary irradiation dose from 1 to 1000 Gy, the OSL yields changes extremely, and the OSL decay kinetics are slowed down. As is well known [2], high-dose irradiation of α-Al_2O_{3-d} induces filling of deep traps, causing a chromium 580 K peak and high-temperature 830 K peak with a 720 K shoulder. The light sum of these TL peaks depends on the growing sample technology of α-Al_2O_{3-d} and the impurities composition [3]. In particular, the TL peak at 830 K after high-dose irradiation is found only in a part of the detectors [3]. The goal of this paper is to carry out comparative studies of OSL and phototransfer effects in strongly irradiated α-Al_2O_{3-d} crystals with an 830 K peak and without it.

It was found that strongly irradiated ($D \geq 50$ Gy) α-Al_2O_{3-d} crystals with TL peak at 830 K and without it have significantly different OSL properties under optical stimulation by blue light with λ_m = 470 nm and deliver irradiance E=10 mW/cm^2 at the sample. In samples with a peak, OSL kinetics has a more complicated form. There is a 2-3 seconds rise-up at the initial stage, then the stages of fast and then sufficiently slow decay with time constants τ_1 = 11-13 s and $\tau_2 \geq 78$ s are observed. OSL kinetics of samples without an 830 K peak contain predominantly fast attenuation components with τ_1 = 11-13 s. It has been established that the fast decay component in the OSL kinetics of the samples of both types is due to the emptying of the main trap and the slow decay component is a result of deeper traps responsible for TL peaks with T_m > 500 K. It is shown that the OSL rise-up is caused by the phototransfer of charge carriers from deep traps to the main one. The most probable source for a phototransfer under optical stimulation with λ_m= 470 nm is a trap responsible for the TL peak at 660 K.

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Spectral properties of irradiated pure NaCl polycrystals

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Sodium chloride (NaCl) is an alkali halide material, which shows pronounced thermoluminescence (TL) and optically stimulated luminescence (OSL). For this reason, it is considered for various dosimetry applications. This work presents results of spectrally resolved thermoluminescence (SR-TL) measurements of pure NaCl polycrystals (pellets) in temperature range 300-550 K for various doses of beta irradiation. Before the irradiation the crystals were annealed for 1 h in 773 K or 923 K in the air and then immediately cooled to remove any storage effect and to obtain enhanced luminescence signal. All irradiations were done at room temperature by ^{90}Sr/^{90}Y beta source with activity of 2.9 GBq. After irradiation any exposure to ambient light was avoided. The SR-TL measurements were carried out in a vacuum using optical chamber with quartz windows, using heating rate of 0.7 K/s. The intensity was monitored using SP150 spectrograph (Acton Research) connected to PIXIS 256E cooled camera (Princeton Instruments), chip format 1024 × 256, sensitive in the spectral range 190-1080 nm. Filter KG5 (Schott) was used to cut off thermal infrared radiation emission above 700 nm. The filter reduces also emission spectrum in UV region below 330 nm and practically cuts it off below 300 nm. Obtained spectra were numerically calibrated with respect to spectral position and luminescence intensity of the measurement system.

Using the annealing temperature of 773 K and a dose of 500 Gy we obtained the SR-TL spectrum consisting of one 3D peak with the temperature of maximum at 440K and the wavelength of maximum at 400 nm. A second, less intensive peak occurs in the temperature range 310-360 K and the wavelength range 330-600 nm (the lowest value of the wavelength range is determined by KG5 filter). The luminescence intensity of this material is much stronger for higher annealing temperatures.

Using the annealing at 923 K and applying the same dose of 500 Gy, we got the SR-TL about 13 times greater. The 3D spectrum is more complex, consisting of several maxima, with the highest signal intensity corresponding to 420 K and 426 nm. The whole spectrum is shifted to longer wavelengths. The shape of SR-TL of NaCl pellets annealed at 923K strongly depends on applied dose, being less complex for lower doses. Detailed numerical analysis of the SR-TL data reveals several elemental temperature and wavelengths peaks corresponding to a complex structure of traps and recombination centers.

The effect of surface states on energy transfer and deep-level luminescence in zinc oxide ceramics

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Zinc oxide (ZnO) has gained significant attention as a promising candidate for opto-electric applications. Luminescence of ZnO, generally, has two bands: near band edge luminescence, ascribed to excitonic emission, and deep level (DL) luminescence with a maximum in the green spectral range, therefore often called green luminescence. The origin of the DL emission is usually associated with intrinsic point defects. However, the exact type of the defects as well as the excitation mechanism of the emission is still a matter of debate due to complex properties of this emission. Several models [1,2] have been suggested to explain these properties but the proposed mechanisms are still controversial.

This work is focused on peculiarities of the properties of the DL luminescence with the aim to elucidate the corresponding energy and charge transfer processes. The studied samples have a form of ceramics manufactured by the uniaxial hot pressing method in a high-temperature vacuum furnace. Excitation and emission spectra, the rise and decay of the luminescence intensity, as well as their temperature dependencies are studied under X-ray and optical excitation. The analysis of the obtained data leads us to the conclusion that complex properties of the DL luminescence, which is usually observed in polycrystalline ZnO materials, are a result of energy transfer between grains core and boundaries due to a non-uniform spatial distribution of luminescence centers and point defects. A qualitative model of such energy transfer is presented and discussed in the report.

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Advantages and limitations of the stimulation with the band shape modulation in OSL measurements

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When one uses for the OSL stimulation the light source with a finite width of the spectral band, the optical cross-section (OCS) itself is not a parameter that governs exclusively the OSL process but rather a quantity that can be called the effective optical cross-section (EOCS). It is a kind of weighted average of the OCS value over the range of the stimulation band used in measurements [1]. The weights in this averaging are determined by the stimulation band shape. In such a case the changes of the shape of the stimulation band, which cause the changes of the EOCS, can be used to control the OSL process in order to improve the separation of the OSL signal originating from different traps [2]. Two methods were intensively studied before, one using continuous changes of the stimulation energy (the variable energy of stimulation OSL, VES-OSL) [2] and another using the linear heating of a sample (the thermally modulated OSL, TM-OSL) [3]. As was shown, the common advantage of all methods that exploit EOCS changes during optical stimulation is not only the effective separation of different OSL components but also a fact that the OSL curves obtained for a defined trap are uniquely determined by its parameters. In the case when the simplest model of the participation of lattice vibrations in the electron transition from the trap to the conduction band is considered, those parameters are: the optical depth of trap, the energy of lattice vibration mode associated with the trap and the Huang-Rhys factor that can be interpreted as an average number of phonons participating in the transition. Estimation of these parameters makes possible a direct correlation of traps identified in the OSL and the TL measurements. While the previously described methods require either an advanced measuring system with strong tunable light source (VES-OSL) or heating that in some cases can also be problematic (TM-OSL), the method using changes of the stimulation band can be realized technically in a very simple way by using at least two sources of light with various spectral bands. Such a method of stimulation can be called band shape modulation OSL (BSM-OSL). Here, results of the BSM-OSL process simulations will be demonstrated for a wide range of trap parameters. The aim of the study is to indicate the limitations of the method and the best experimental conditions for the effective separation of OSL related to different traps.

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Growth and luminescent properties of Tb and Eu doped YAP, LuAP, GdAP and TbAP mixed oxides crystals prepared by micro-pulling down method

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Perovskite-structured compounds are well-known host materials for different rare earths (RE) dopants. Among them, the RE doped $YAlO_3$ (YAP) perovskite is of particular interest, because of a wide range of its potential applications including scintillators and laser materials. RE doped single crystalline films (SCFs) and thick crystal plates of YAP and LuAP can be also applied as scintillating screens for visualization of X-ray images.

Within this work, the SCs of undoped and Tb^{3+} and Eu^{3+} doped $Y_{1-x}A_xAlO_3$ (A = Lu, Gd, Tb; x = 0, 0.5, 1) mixed perovskites were grown by micro-pulling down method at the IFJ PAN, Krakow. The SCs were grown from the Mo crucible at the growth rate of 0.2 mm/min in the inert gas atmosphere. The obtained SCs had around 3.5 mm diameter and up to several cm length. The structural quality was studied using X-ray diffraction. The properties of Tb and Eu doped crystals were compared with the properties of respective SCFs.

The luminescent properties of SCs and SCFs perovskites under study were characterized by cathodo- (CL), photo- (PL) and thermo- (TL) luminescence spectra. The scintillation light yield and decay kinetics under excitation by alpha particles have been also investigated. The temperature and wavelength resolved TL spectra were measured after the samples irradiation with both beta and alpha particles.

We have found that the shape of CL and PL spectra as well as decay kinetics of the Eu^{3+} luminescence in the RAP:Eu (R = Y, Lu, Gd, Tb) perovskites are strongly affected by the local surrounding of dopant. For characterization of the distortion of Eu^{3+} local surrounding, the *asymmetry ratio* K between the intensities of respective transitions has been measured. It was found that K value is large (1.9 - 2.0) in the case of RAP:Eu (R= Lu, Gd, Tb) perovskites and significantly smaller (0.45) in YAP:Eu.

It was confirmed that Eu doped mixed perovskite crystals practically do not exhibit the TSL signal in the UV-VIS spectral ranges at measureable level for both radiation types. In turn, CL spectra showed quite strong luminescence of Eu^{3+} ions in red range. TL measurements performed for Tb doped samples showed a significant emission in the UV-VIS spectral range with the most prominent TL peak at around 220 ^{o}C. The measured TL spectra exhibit typical luminescence of Tb^{3+} ions in the green range.

Luminescence mechanism and energy transfer in cesium metavanadate $CsVO_3$

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Vanadates are well known as efficient impurity and self-activated luminescence materials. Among them, cesium vanadate $CsVO_3$ is a promising multifunctional compound that can be synthesised through the various relatively easy applicable synthesis techniques. Particularly, cesium vanadate attracts considerable attention due to the presence of unique luminescence properties related to the strong self-activated broad band emission that may be used for conversion of UV radiation into the yellow-green emission. The compounds of such type show promise as phosphors for X-ray imaging, UV dosimetry and white LED with blue or near UV-excitation.

The intrinsic luminescence in vanadate (V^{5+}) compounds is established to be due to the electronic transitions from the $^3T_1$ and $^3T_2$ triplet excited states to the $^1A_1$ ground state (in terms of the molecular orbital theory) in $[VO_4]^{3-}$-groups. However, the nature of relaxation process occurred from the excited states of $[VO_4]^{3-}$ group has not been fully understood so far. In this report we present the results of the time-resolved radio- and photoluminescence study aimed to get insight into the luminescence mechanism and energy transfer in $CsVO_3$ synthesized through the solid state reaction techniques with modification by laser ablation method.

By varying the synthesis regimes we produced $CsVO_3$ microcrystalline powders with grain sizes ranged from 0.5 to 2 μm and from 3 to 20 μm. The quality of powders was evaluated with XRD and SEM methods. The luminescence spectroscopic properties of the samples were investigated upon X-ray, pulse cathode beam, pulse laser and pulse xenon arc lamp excitation. The luminescence decay times were measured upon excitation with an Ekspla NT 342B OPO laser at Utrecht University (the Netherlands).

The lifetime measurements clearly demonstrate different relaxation dynamics for various excited states in $[VO_4]^{3-}$-groups. The latter is connected with different pathways for relaxation of excited singlet states $^1A_1 \rightarrow {}^1T_1$ and $^1A_1 \rightarrow {}^1T_2$ in metavanadate. The temperature dependencies of emission lifetime and luminescence intensity are discussed in terms of the effects observed. Basing on these results, some features of the luminescence mechanism and energy transfer in cesium metavanadate $CsVO_3$ are discussed. An extended model of relaxation processes is proposed.

Fast cathodoluminescence of diamond micropyramids

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There is a wide range of fields interested in luminescent diamonds: quantum information technologies; optical biomarkers, and scintillators (X-ray beam monitors). Intense hard x-ray pulses at high repetition rates of >100 Hz at new generation light sources such as x-ray free-electron lasers or insertion devices at 4 th generation storage rings formulate new requirements to the scintillators to be used to monitor their radiation: fluorescence decay time faster than 100 ns; low Z, exceptional radiation hardness and high thermal conductivity to withstand intense hard x-ray pulses at high repetition rate. Diamond materials offer a variety of fast fluorescence types, which potentially can be of interest for such applications.

Here we present recent results of cathodoluminescence study performed with a pulsed source on self-supporting diamond films of new morphology composed of diamond micropyramids produced by the combination of chemical vapor deposition technique and selective oxidation. The spectrum of cathodoluminescence was dominated by a fast wide band peaking at 430 nm. This luminescence had a nonexponential decay, which could be fitted b y three components with τ 0.4, 4 and 15 ns. In the literature this band is known as A-band and for the first time was observed some 30 years a go. However we didn't find any data on characteristic decay time of this luminescence, thus it was determined for the first t ime. The origin of A-band was initially explained by donor-acceptor recombination, later on it was attributed to dislocations and other imperfections of the crystal. It was opposed to excitonic emission: in high-quality crystals excitonic emission was observed while in those with dislocations A-band was dominating and excitonic emission was absent. This was different in our case: we did observe both excitonic emission (narrow band peaking at 236 nm) and the "A-band" at 430 nm. This could be due to the non-uniform distribution of luminescence centers along the pyramids - this is the assumption to be verified during further studies. Well-known narrow luminescence lines attributed to N-V centers (576 nm, FWHM 3 nm) and Si-V centers (738 nm, FWHM 4 nm) were observed as well and their characteristic decay times determined: it was 3 ns for the N-V luminescence and 4 ns for Si-V luminescence.

The effect of growth conditions is verified and discussed and comparison with "conventional" diamond samples is presented.

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Investigation of La and Gd Oxyfluorides by Luminescence Spectroscopy

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According to the band structure calculations La and Gd oxyfluorides are wide band gap insulators with a peculiar structure of valence bands split in several sub-bands, which can facilitate fast intraband luminescence transitions [1]. However, there is nearly no experimental information on luminescence studies of these interesting materials allowing to determine nature of intrinsic excitations and such important parameters as value of the energy gap, etc. We performed photoluminescence studies of La and Gd oxyfluoride powders under UV-VUV excitation and pulsed cathodoluminescence with sub-nanosecond time resolution [2]. The nature of various intrinsic and impurity emissions and important parameters determined will be discussed.

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Cathodoluminescence study of LuAG:Ce,Mg and LuGAGG:Ce,Mg single crystalline films – Mg-rich extension

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Cerium activated lutetium aluminum garnet (LuAG:Ce) is a promising material for applications in detectors of ionizing radiation. This is mainly due to its high light yield (LY) of 25 kph/MeV, short decay time of 60-80 ns, high atomic density (6.7 g/cm^3), and high radiation stability with no hygroscopicity. The cathodoluminescence (CL) performance can be improved by Ga and Gd doping the garnet matrix. Proper admixture of these elements can increase the LY to 50-60 kph/MeV in addition to eliminating unwanted slower decay components. There was an idea that further decay acceleration can be achieved by doping the garnet with monovalent (Li^+) or divalent ions (Mg^{2+}, Ca^{2+}). This should increase the valency of some Ce^{3+} centers to Ce^{4+} which should better compete with electron traps and thus accelerate the decay. Our previous work proved the same decay trend [1], however, at a price of the LY. Such LY loss may induce the idea, if the stable Ce^{4+} centers are really participating in Ce^{3+} emission. To verify this idea, Mg-rich LuAG:Ce,Mg and LuGAGG:Ce,Mg single crystalline films were prepared. They were grown by the liquid phase epitaxy on bulk single crystal LuAG substrates. As a result, thin films with thickness around 10 μm with different concentration of Mg were prepared. CL was selected as an optimal tool for luminescence study. This ensures enough energy to excite over bandgap (contrary to photoluminescence) with sufficiently low penetration depth (contrary to radioluminescence) to prevent the substrate excitation. CL apparatus was used for this purpose [2]. CL emission spectra and CL decays were studied at presented specimens. The general trend of decreasing LY and accelerating decay to only units of ns was observed. However, it was shown that characteristic 5d-4f emission at Ce^{3+} still occurs, even at high concentrations of Mg (> 6000 ppm). This is a very important result in comparison with optical absorption spectra because these Mg-rich films don't show any of the two characteristic absorption bands belonging to 4f-5d transfer at Ce^{3+}, so the vast majority of Ce^{3+} centers are already converted into Ce^{4+} ions. This means, that Ce^{4+} ions must play a significant role in Ce^{3+} emission mechanism.

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Luminescence and scintillation characteristics of Ce3+ - doped (60 -x)SiO2 -20Al2O3 - xBaF2 - 20Gd2O3 glasses

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Ce^{3+}-doped glasses with compositions (in mol.%) of (60-x)SiO_2- 20Al_2O_3 - xBaF_2-20Gd_2O_3 were prepared by melt quenching under a CO reduction atmosphere [1]. A broad emission band of the Ce^{3+} 5d 4f transition peaking around 385 nm was observed in the photo- and radio-luminescence spectra. The integral scintillation efficiency about 45 % of the $Bi_4Ge_3O_{12}$ scintillator was obtained for a 10%BaF_2 glass sample. Light yield (LY) and its dependence on an amplifier shaping time [2] were measured under excitation with rays. At 662 keV gamma rays, the 10%BaF_2 glass shows a LY of 1590 photons/MeV and energy resolution of 16.5%. The dependence of LY on sample height was also measured and light loss coefficient was estimated [3].

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Epitaxial growth, photoluminescence and scintillation properties of Pr3+ doped YAlO3 single crystalline films

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Inorganic scintillators have found their application in many emerging fields such as high-energy physics, medical imaging, geological exploration, and homeland security. Increased needs for better scintillators have triggered the development of new fast and efficient scintillation materials [1]. In this direction, the Pr^{3+} doped perovskites have been considering as good scintillators [2]. The single crystalline films could provide better spatial resolution compared to powder phosphor screens due to eliminating light scattered by phosphor particles. Liquid phase epitaxial (LPE) technique is a versatile method suitable for the growth of high quality single-crystalline films on suitable substrate, it is more flexible compared to growth of bulk single crystals by Czochralski or Bridgman methods [3]. In this work, a set of Pr^{3+} -doped $YAlO_3$ epitaxial films have been grown by the LPE technique at different Pr^{3+} concentrations and growth conditions, where the $PbO\text{-}B_2O_3$ was used as flux. The optical, photoluminescence (PL), radioluminescence, photo-electron yield, PL and α -decays have been carried out. At 215 nm excitation or upon X-ray excitation, the intense emission has been observed at 245 and 280 nm due to 5d →4f (Pr^{3+}) transition. The PL and α- decay curves exhibit single exponential nature with mean decay time around 7 ns in samples with optimized composition. Photo-electron yield is found around only 16% (110 Ph/MeV) compared to reference single crystal YAP:Ce due to impurity lead ions quenching effect. The results show that the prepared films could be useful for fast scintillation applications.

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Influence of optical bleaching on trapping and recombination properties in beta irradiated potassium chloride pellets

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Alkali halides are well-known wide band gap (Eg = 8-12 eV) materials, which are very important for luminescence dosimetry. Many of them exhibit pronounced thermoluminescence (TL) and optically stimulated luminescence (OSL) after irradiation by high-energy photons or particles [1]. Differently doped LiF detectors, e.g. LiF: Mg,Ti and LiF: Mg,Cu,P are the most sensitive and stable TL detectors [1, 2].

The well-known sodium chloride (table salt) also exhibits strong defect-related luminescence. For this reason NaCl was considered for its potential use for retrospective and accidental dosimetry. It was shown also, that the natural mineral (halite) allows determination of the age of sediment formation and thus tracing climate changes and geomorphology processes occurring. Unlike NaCl, the KCl luminescence properties are much less known. The material was investigated mainly in its doped form, primarily with europium. This material was considered as two-dimensional X-ray and UV imaging sensor as well as dosimeter in radiotherapy [3].

KCl pellets were prepared from analytical quality potassium chloride powder (99.5%) (Chempur). Before the irradiation the pellets were annealed for 1 h in temperature 500°C in the air and then immediately cooled to remove any storage effect. All irradiations were done at room temperature by ^{90}Sr/^{90}Y beta source with activity of 2.9 GBq. Then, the samples were bleached by green LEDs during routine CW-OSL readout for various periods of time. Finally, the measurements of spectrally resolved thermoluminescence (SR-TL) were performed [4]. The measurements were carried out in a vacuum at the temperature range 300-550 K using KG5 filter (Schott) to cut off thermal infrared radiation emission above 700 nm. Obtained results are very interesting. Green light significantly affects the TL spectra but some traps are still populated after 45 min. bleaching. Emission bands are stable, however green light activates additional recombination band in the UV region.

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EPR and Luminescence Spectroscopy of Mn^{4+} Doped K_2SiF_6

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The Mn^{4+} doped fluorides have gained a lot of interest in LED applications for displays and lighting [1]. These materials can provide narrow-band red emission needed for next generation warm white LEDs, which are capable of emitting warm white light similar to thermal light sources and are perceived as cozy by humans. According to the recent review [1], there are still scatter of the determined values on such important parameters as thermal quenching temperature, decay time of Mn^{4+}, etc. depending on the conditions and regimes used in preparation of such phosphors. The aim of this study was to understand the underlying processes of such behavior of K_2SiF_6 phosphor, determining its performance.

The Mn^{4+} doped K_2SiF_6 phosphor was synthesized using room temperature co-precipitation in alcohol-water mixtures. Additionally, pure K_2SiF_6 was studied in order to distinguish the effects due to the Mn^{4+}doping and reveal the native defect centers present in the material, which may influence the dopant luminescence. The phase purity and morphology of powders were studied by XRD, Raman and SEM techniques. The electronic properties of pure and doped K_2SiF_6 were investigated by luminescence spectroscopy under visible to VUV excitation in a wide temperature region of 77 K to 800 K. The EPR experiments were carried out with a Bruker CW X-band spectrometer in the temperature region of 4 - 300 K. The ENDOR experiments were carried out to resolve the interaction between Mn^{4+} ion and the neighboring fluorine ions. In a complicated EPR spectrum Mn^{4+} and F hyperfine lines were observed. Temperature dependence of Mn^{4+}emission (incl. decay time), structure details and the values of the EPR parameters obtained for the manganese and defect centers will be discussed.

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Scintillation properties of composite scintillators based on diamond micropowders

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For detectors applied in medical and inspection equipment and in high energy physics experiments, scintillators with high radiation hardness, short decay times, low afterglow level and others are required. Diamond powders meet these requirements since the crystalline framework of diamond determines its high chemical and radiation hardness. Composite scintillators based on diamond micropowders could become an alternative to existing scintillators in a number of applications.

In this paper, scintillation properties of composite scintillators based on diamond micropowders in a polysiloxane matrix are studied. Diamond micropowders of various fractions and forms were obtained by spontaneous synthesis at temperatures above 1000 °C and at high pressure. Fe, Co, Ni were used as solvent metals of carbon.

The study of the luminescence spectra of composite scintillators have shown the existence of luminosity in the visible range, both at the excitation with ultraviolet radiation and when excited with X-rays or an electron beam. It is noted that at the liquid nitrogen temperature nickel centers with a wavelength of 484 nm and 884 nm dominate in the spectra. The presence of nickel centers allowed keeping the luminescent properties even after irradiation of the samples with electrons with energy of 8.3 MeV of the cumulated dose of 50 Mrad and 100 Mrad, which gives evidence of their high radiation hardness. It was found that when irradiated with a cumulated dose of 50 Mrad, the samples without nickel centers have lower luminescence intensity. The presence or absence of nickel centers does not affect the decay time of the samples under study, which is about 17-22 s. The afterglow of composite scintillators after irradiation with x-ray of 140 kV after 100 ms was not more than 0.02%.

Energy transfer from Ce^{3+}* to Er^{3+} in YAG host

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We present our results made on well-known YAG:Ce (Y3Al5012 doped with Ce^{3+}) scintillator intentionally codoped with Er. We show that the energy transfer from Ce^{3+*} to Er^{3+} is significant and lead to the decrease of Ce^{3+*} emission decay time below 30 ns (less than half of the decay time of YAG:Ce). The decay kinetics is correctly modelled by Förster-Dexter model. This kind of energy transfer is enabled by the overlap of the Ce^{3+*} emission and Er^{3+} absorption spectra, respectively. Quantitative comparison of the decays of seven samples with different Er concentration (0-5wt%) allows us to compute the critical acceptor concentration. This result is very important for tailoring the decay time of a YAG:Ce:Er phosphor.

The presented results are the absorption and luminescence spectra, together with photoluminescence decays. The decay kinetics show significant departure from pure monoexponential form (for the case of YAG:Ce), in agreement with the Förster-Dexter model. This is a direct proof of the energy transfer mentioned before.

Time-resolved luminescence spectroscopy study of nanoceramics MgAl2O4:Ce

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Ceramic scintillators, with their broadly tunable properties are advanced materials for different applications. Transparent ceramics have been for use in medical and industrial detectors for computed tomography scanning applications [1]. Magnesium aluminate spinel (MAS) $MgAl_2O_4$ is a promising material for scintillators due to good transparency, non-hygroscopicity, absence of birefringence, resistance to neutron radiation [2]. The purpose of this work is to study the effect of cerium concentration on the luminescent properties of transparent ceramics $MgAl_2O_4$, produced with using by a spark plasma sintering (SPS) technique [3]. The MAS transparent ceramics undoped and doped with CeO_2 (0.005 to 0.1 wt%) have been investigated. High-purity (higher than 99.999%), $MgAl_2O_4$ powders (purity 99.999%, average particle size 200 nm) were used as the starting materials. Cerium oxide CeO_2 powder (purity 99.95%, average particle size 100 nm) was used as the dopant. The powder was consolidated using a spark plasma sintering machine SPS 515S (Syntex Inc., Japan), vacuum at P=10^{-3} Pa, at T=1300 °C, a pressure of 72 MPa. An electron beam with a pulse duration FWHM 10 ns, with an average electron energy of 250 keV, was used to excite cathodoluminescence (CL). The CL pulse was registered with an optical spectrometer consisting of MDR-3 monochromator, FEU-84-6 photomultiplier and LeCROY 6030A oscilloscope. The CL spectra registration in the "time window" was carried out by a spectrometer AvaSpec 2048L-USB2 (200-1100 nm, inverse linear dispersion 1.2 nm / mm) after one exitation pulse. Synchronization was carried out by the GI-1 generator. The CL spectra of MAS with different concentrations ions Ce^{3+} were measured. The luminescence decay in different spectral ranges is studied. A wide band with a λ_{max} at 430 nm is observed in the spectrum. The emission of impurity Cr^{3+} ions was recorded. Fast CL with a λ_{max} at 370 nm (τ=330 ns) is observed. The dependence of the luminescence properties of nanoceramics on annealing conditions has been studied. The nature of the luminescence bands, the processes of excitation energy transfer in nanoceramics $MgAl_2O_4$:Ce are discussed.

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Luminescence properties of Lu_2O_3:Eu and Lu_2O_3:Tb nanopowders and films

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The aim of our work is to compare the sintering processes and luminescent properties of Lu_2O_3:Eu and Lu_2O_3:Tb NPs and films using the traditional spectral methods (cathode- and photoluminescence). The NPs of these compounds were prepared pressure-assisted hydrothermal processing. The films were prepared using spin-coating method. The structure and morphology of NP and films were confirmed using XRD diffraction and scanning electron microscopy, respectively. Specifically, the significantly different morphology of NPs of the two compositions is observed even apparently the same condition of preparation: ball-like particles are formed in the case of Lu_2O_3:Eu and dendrite-like structures in the case of Lu_2O_3:Tb.

The lattice structure of Lu_2O_3 provides two sites with different symmetry for Eu^{3+} and Tb^{3+} dopants. Namely, the centrosymmetric C_{3i} (S_6) and low-symmetry C_2 sites. Generally, for the C_{3i} sites the electric dipole 4f-4f transitions are forbidden and emission spectra of the Lu_2O_3:Eu and Lu_2O_3:Tb NPs are dominated by transitions of Eu^{3+} and Tb^{3+} ions occupying the C_2 sites [2] unless direct selective excitation into the C_{3i} site is applied. Meanwhile, the Eu^{3+} and Tb^{3+} luminescence can be different in the various Lu_2O_3 crystalline forms mainly due to the presence of oxygen vacancies as emission and trapping centers [1].

We have found that the PL emission spectra and PL decay kinetic of Lu_2O_3:Eu NP and films at RT are quite similar at different excitation energies and consist of the group of lines caused by the $^5D_0 \rightarrow ^7F_j$ transitions of Eu^{3+} ions. The most intensive peak is observed at 610 nm, which corresponds to the $^5D \rightarrow ^7F_2$ transitions. No emission of Eu^{2+} ions was detected in the Lu_2O_3:Eu NP. In opposite, the PL emission and excitation spectra as well as PL decay kinetic of Lu_2O_3:Tb NP at 300 K shows two types of Tb^{3+} centers with the main emission peaks at 542.4 and 544.0 nm and corresponding maxima of excitation bands located at 270 and 305 nm. Their decay times are 1.83 ms and 10.5 ms for Tb(C_2) and Tb(C_{3i}) centers, respectively.

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Energy conversion in $LiSrPO_4$ doped with Pr^{3+} ions

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In this paper, we report on luminescence spectroscopic characterization of $LiSrPO_4$ doped with Pr^{3+} ions, that we found potentially attractive for scintillation applications. Studied samples were synthesized using a solid state reaction and XRD verified in University of Verona (Italy). The spectroscopic study included measurements of photoluminescence (PL) and X-ray excited luminescence (XRL) spectra in the range of 1.5-6 eV as well as UV-VUV PL excitation spectra in the 3.5-10 eV range at temperature of 10, 90 and 300 K. The UV-VUV excited measurements were performed at Beijing Synchrotron Radiation Facility (BSRF, China). Luminescence decay kinetics were recorded upon pulse cathode excitation (FWHM 200 ps, frequency 5 Hz) using an electron gun. XRL spectra and X-ray excited decay kinetics upon high-frequency (8 MHz) X-ray synchrotron radiation excitation were recorded at VEPP-3 storage ring (BINP, Novosibirsk, Russia). In addition, thermally stimulated luminescence was studied by recording glow curves in the temperature range 90 - 650 K.

PL spectra of $LiSrPO_4$:Pr^{3+} (1%) recorded upon UV-, VUV-, X-ray or e-beam excitation are composed of two emission bands in UV-region centered near 245 and 264 nm with different Stokes shifts that correspond to interconfigurational $5d \rightarrow 4f$ transitions in Pr^{3+} ions. Emission in visible region is presented by intraconfigurational $4f \rightarrow 4f$ transitions observed in temperature range of 10 - 295 K.

Under high-frequency X-ray excitation, the XRL decay kinetics of $5d \rightarrow 4f$ transitions has a non-exponential decay (9.3 and 30 ns) and reveals the presence of a relatively intense slow component appearing as a background. Upon cathode beam excitation the decay kinetics of $5d \rightarrow 4f$ emission is dominated by a fast component (19 ns) while the contribution of the slow decay component does not exceed 1%. The UV-VUV PL excitation spectra recorded for *d-f* and *f-f* emission features reveal peculiarities associated with host-to-impurity energy transfer processes. Based on the measurements of the pronounced thermoluminescence curve, the parameters of the charge carrier capture centers were calculated. Their role in the processes of energy transfer to Pr^{3+} centers was analyzed.

Complex Spectroscopic Study of $Li_6Y(BO_3)_3$ Single Crystals Doped with Praseodymium

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Borate crystals often demonstrate several advantageous properties making them convenient for synthesis and suitable for various applications. They are recognized for low synthesis temperature, high optical quality, transparency in a wide spectral range up to vacuum ultraviolet, and high radiation damage threshold [1]. All these properties make them perspective also for dosimetry and scintillation applications. Single crystals of lithium yttrium borate (LYB) having a monoclinic structure and belonging to the $P2_1/c$ space group are excellent materials for laser applications due to an easy incorporation of rare-earth dopants (e.g. Yb^{3+}, Er^{3+}, Eu^{3+}, Nd^{3+}) into the yttrium sites. Praseodymium doped LYB single crystals have not been studied yet. Some results on another double borate, a polycrystalline $Li_6Lu(BO_3)_3$:Pr phosphor, have been reported earlier [2].

In the present work, complex investigation of cathodoluminescence (CL), photoluminescence (PL) and thermostimulated luminescence (TSL) properties of $Li_6Y(BO_3)_3$:Pr(1 mol%) and $Li_6Y(BO_3)_3$:Pr(10 mol%) crystals grown by the Czochralski method [3] will be presented. An X-ray fluorescence analysis confirmed a very high purity of the grown crystals. The TSL and CL spectra were measured in a wide temperature range of 4.2-650 K and compared to those recorded under photoexcitation.

Emission bands caused by the $\boldsymbol{f} \rightarrow \boldsymbol{f}$ and $\boldsymbol{d} \rightarrow \boldsymbol{f}$ electronic transitions of the Pr^{3+} ions were successfully identified in the luminescence spectra. Their excitation spectra were measured in the range of 2.5-10.5 eV. The $\boldsymbol{d} \rightarrow \boldsymbol{f}$ emission is overlapped by a defect emission of yet unknown origin. Time-resolved CL and PL methods were used to study the decay kinetics of the $\boldsymbol{d} \rightarrow \boldsymbol{f}$ emission having the lifetime of about 9 ns. TSL measurement revealed a number of peaks in a wide temperature range of 5-650 K. The model of various emission centres will be discussed.

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Optically stimulated luminescence of LiF:Mg,Cu,P with different dopants composition

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The optically stimulated luminescence (OSL) is besides thermoluminescent (TL), a very well-known method used for dose measurements in radiation protection dosimetry. Especially in recent years, the attractive OSL technique properties, enhanced its application for dosimetry purposes. Lithium fluoride (LiF) passive detectors has so far been used mainly for TL dosimetry. However, it turned out that they can serve also as a OSL tool for passive dose measurements, giving quite substantial signal sensitivity, compared to other kind of OSL materials [1]. Recently, LiF:Mg,Cu,P (MCP) was also used as a OSL powder, embedded inside the transparent silicone matrix elastomer, create a novel method which can be potentially used for measuring even 3D dose distribution based on OSL technique [2].

It should be emphasized that the MCP powder, was developed years ago strictly for TL applications and their OSL properties are in fact a kind of side effect, which so far has never been deeply investigated, especially at an angle of its OSL properties. This means that the used dopants concentrations, were selected and optimized for thermoluminescent, not for optoluminescence. One can therefore assume that such OSL properties can be modified and improved by changing dopants composition [3].

In attempt to resolve this issue and hence to increase the potential LiF:Mg,Cu,P optoluminescences applications, a comprehensive study of the influence of particular dopants composition was performed. The presentation will show the results of the first step of the project, in which the LiF:Mg,Cu,P powder, originating from a large variety of dopants composition was studied, from viewpoint of their OSL properties. The numerous OSL glow curves of the samples excited with different types of ionizing radiation, exploiting different OSL modes, such as continues (CW-OSL) and time-resolved OSL (TR-OSL) has been investigated.

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Spectroscopic studies of the Bi^{3+}-Eu^{3+} co-doped GGG as a UV-to-Vis converting phosphor for white LEDs

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Recent studies of photoluminescence characteristics of Bi^{3+}-doped $Gd_3Ga_5O_{12}$ (GGG) [1] revealed that no UV emission, which could be ascribed to the radiative decay of the triplet excited state of Bi^{3+}, is observed in this material. Instead of this, a broad emission band in visible range centered at 480 nm is observed at UV excitation of the material. Two components of this emission (main one with maximum at 480 nm and weaker one at 505 nm) were shown to be of exciton origin and related with the radiative decay of an exciton localized around a single Bi^{3+}ion and a dimer Bi^{3+} - Bi^{3+} center, respectively [1].

The present work presents results of characterization of the GGG:Bi^{3+} and GGG:Bi^{3+},Eu^{3+} phosphors as possible candidates for UV-to-Vis converting phosphors for white LEDs. For this purpose a series of powder samples with different concentration of Bi^{3+} ions (from 1 to 6 at.%) and Eu^{3+} ions (from 0.2 to 1 at.%) were synthesized by solid-state reaction at 1350-1500 °C and studied by spectroscopic techniques. In particular, photoluminescence (PL) spectra and decay kinetics, photoluminescence excitation (PLE) spectra and quantum efficiency (QE) of luminescence of the materials were measured. The CIE chromaticity coordinates as well as color rendering index (CRI) of the studied materials were calculated as well.

Obtained results demonstrate a possibility of the emission color tuning from blue to orange-red at 280-320 nm excitation by the way of changing of $Bi^{3+}$and Eu^{3+} concentrations. In particular, the highest CRI of 87% was obtained for the sample with nominal composition of GGG:Bi(2%),Eu(0.2%), at the same time the most white color emission (CIE 1931: 0.358, 0.313) was observed for GGG:Bi(2%),Eu(0.5%).

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Deterioration of scintillator energy resolution due to fluctuations of track structure and a way to improve it by kinetic waveform analysis

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The energy resolution of scintillators for many crystals is far from the theoretical limit. Even the account for scintillator non-proportionality (i.e. the dependence of the scintillator yield on the energy of ionizing particle) can only partially explain large values of energy resolution. One of the possible important inputs to energy resolution is fluctuations of track structure connected with relatively rare events. For instance, deep K-levels are excited not for every 500 keV electron track in CsI. The Auger relaxation of such hole produce additional high-energy electron resulting in effective branching of the track and decrease the mean energy in each branch and, therefore, higher densities in track with branches. Production of delta-rays, i.e. large-angle scattering of primary electron with production of recoil electron, also result in track branching. These events modify the structure of the track (namely, increase the branching) and therefore significantly modify the density distribution of excitations in track region [1]. The track is characterized by different structural parameters, from the distribution of densities of excitations to fractal dimensions of e-e, h-h and e-h distributions. If a track is characterized by larger volume with dense excitations, the quenching increases and modifies the decay kinetics at time below radiation one. The larger volume of low-density regions results in increase of long components of scintillation decay. Therefore, scintillation decay profile for each event partially correlates with the structure of the track, and the weighting of different components of the decay could improve the energy resolution of scintillator [2,3]. The simulation of these effects demonstrates that Fano factor for emitted and registered photons becomes significantly larger than Fano factor for the number of electron-hole pairs, and therefore the statistics of photons becomes non-Poissonian. The weighting of signals obtained by the integration of scintillation signal over different time gates allows to achieve the reduction of the energy resolution in comparison with integration of the signal over the whole shaping time.

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Luminescence and scintillation properties of hafnium and lutetium oxide nanocrystals: overview and possible applications

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We present the optical response of hafnia nanocrystals prepared by non-aqueous sol-gel route following excitation with ionizing radiation in comparison with previous photoluminescence data [1, 2]. By performing a complete spectral analysis, we find the presence of six bands, whose relative intensities depend upon nanocrystals radius that varies with the temperature of annealing treatments. The visible luminescence bands at 2.2 eV, 2.5 eV and 2.8 eV are similar to those detected in [2], while the UV emission at 4.2 eV and 4.6 eV are observed for the first time. The investigation of the temperature dependence of each emission intensity allows us to propose distinct origins for all the emissions. The components lying in the visible-near UV region and displaying the same thermal quenching energy of about 0.08 eV can be related to intrinsic defects. The UV components, with similar thermal quenching energy of 0.23 eV, are likely associated with excitonic transitions. Time-resolved scintillation measurements in the visible range show the presence of a fast decay in the nanosecond time scale in nanocrystals annealed at 450 °C.The displayed properties disclose the potential use of hafnia and hafnia-based engineered nanostructures for different optical applications, including the scintillation field. Moreover, in this investigation we demonstrate that Eu^{3+}doped HfO_2 nanocrystals can be effectively used as non-toxic, highly stable probes for cell optical imaging and, potentially, as radiosensitive materials for clinical treatment [3]. Lastly, we propose a preliminary study on Lu_2O_3:Eu^{3+} nanoparticles, whose high density, high atomic mass, radiation hardness, and environmental stability make them good host for phosphor and scintillating applications.

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Composite thermoluminescent detectors based on the Ce3+ doped LuAG/YAG and YAG/LuAG epitaxial structures

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This work presents the first attempt for the creation of composite thermoluminescent detectors in the form of the epitaxial structures based on the single crystal (SC) and single crystalline films (SCF) of garnet compounds, grown by liquid phase epitaxy (LPE) method. We are considering two combinations Ce^{3+} doped garnets, namely LuAG:Ce SCF /YAG:Ce SC and YAG:Ce SCF /LuAG:Ce SC, grown by LPE method from the super-cooling melt-solution based on the PbO-B_2O_3 flux.

In our recent publications [1, 2] we have shown the possibility of the simultaneous registration of α-particles and γ-quanta by the way of separation of the scintillation decay kinetics of SCF and SCF parts of composite scintillators, based on the epitaxial structures of different garnet compounds. Now we want to show the new possibility for simultaneous registration of the components of mixed ionization fluxes, using differences between the thermoluminescence (TSL) glow curves, coming from SCF and substrate of composite detector. For samples measurement we used the automatic Risø TL/OSL-DA20 reader under α-particles (49.976 Gy) and β-particles (0.97 Gy) excitation of the samples under study.

We observed the significant differences in the position of main TSL peaks of the glow curves of the SCF and SC components of LuAG:Ce SCF/YAG:Ce SC and YAG:Ce SCF / LuAG:Ce SC epitaxial structures after α- and β-particles excitations. For this reason we can expect that the mentioned combinations of the garnet compounds in the respective structures can be used as the prototypes in the development of new generation of composite TL detectors.

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Luminescent properties of Ce^{3+} doped $LiLuP_4O_{12}$ crystals under synchrotron radiation excitation

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Our report presents the result of the investigation of Ce^{3+} doped Lithium Lutetium tetraphosphate ($LiLuP_4O_{12}$:Ce) crystals as new scintillation materials. The Ce^{3+} ions in the Lu positions of $LiLuP_4O_{12}$ host exhibit very strong UV luminescence in the double bands peaked at 336 and 360 nm, related to the $5d^1$-4f ($^2F_{5,2/7/2}$) transition of Ce^{3+} ions.

Two $LiLuP_4O_{12}$:Ce crystals were grown using micropulling down method. For characterization of the luminescent and scintillation properties of these crystals, the cathodoluminescence (CL), photoluminescence (PL), X-ray excited luminescence (RL) and thermoluminescence (TSL) measurements were used. The light yield (LY) of $LiLuP_4O_{12}$:Ce crystals was measured and compared with BGO and YAG:Sc crystal under e-beam, α-particle and X-ray excitation. Namely, the LY of these crystals is comparable with LY of BGO standard crystal. Meanwhile, we are sure that after the optimization of the growth condition the scintillation efficiency of Ce^{3+} doped $LiLuP_4O_{12}$ crystals can be significantly improved.

For investigations of the energy transfer in from $LiLuP_4O_{12}$host to Ce^{3+} ions, in addition to mentioned above traditional spectroscopic methods, the time-resolved luminescent spectroscopy of $LiLuP_4O_{12}$:Ce crystals under excitation by pulsed synchrotron radiation was applied. Using the SR excitation, we also estimated the basic optical characterization of $LiLuP_4O_{12}$ matrixes, such as onset of interband transitions, the band gap value and the energy of creation of an exciton bound with the Ce^{3+} ions.

The influence of magnesium impurity on luminescent and dosimetric properties of alumina ceramics

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Doping of impurities into the initial matrix of the detector material leads to the creation of new luminescent centers, and, consequently, significantly changes the luminescent and dosimetric properties of the material. The introduction of magnesium impurities into the matrix of nanoscale alumina contributes to a decrease in grain growth, which leads to the preservation of radiation resistance inherent in nanomaterials [1]. Ceramics was manufactured in multistage synthesis. Firstly, porous matrices were produced by cold static pressing under pressure 3300 kgf/cm^2 from high purity nanopowder Al_2O_3. The powder was pressed into compacts 10 mm in diameter and 1.2 mm in thickness. Secondly, the porous matrices will be impregnated in the solutions of magnesium nitrate with concentration (0.001-6.85 wt. % Mg in solution). Thirdly, the doping compacts was sintered during duration 2 hours at varying temperatures in a vacuum (0.013 Pa) from 1500 to 1700 ^{o}C and in air from 900 to 1500 ^{o}C.

Pulsed cathodoluminescence (PCL) was measured by spectrometer "KLAVI" at excitation of an electron beam. PCL spectra show that multistage synthesis leads to the formation of luminescent centers in ceramics: intrinsic centers of Al_2O_3 (420 nm), doped centers of Mg (520 nm) and impurity centers of Cr in the initial powder (693 nm). It is established that an increase in the concentration of dopant leads to an increase in the luminescence intensity of 520 nm and a decrease in the 420 nm band.

The electron-beam gun with dose 1.5 kGy per one pulse and the ^{90}Y/^{90}Sr β-source with the dose rate of 52 mGy/min were be used to excite TL. TL curves were obtained by the dosimetry system "Grey" with a variation of the impurity concentration in the solution during doping, the sintering temperature of ceramics, and various doses of ionizing radiation. Three peaks with maxima at 380, 450, and 580 K can be distinguished on the TL curves. An increase in the concentration of the magnesium impurity leads to a significant increase in the intensity of the peak at 380 K. Dose dependences for the electron source in the range 1.5-75 kGy and for the ^{90}Y/^{90}Sr β-source in the range of 0.8-300 Gy are obtained.

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First-principles calculations of optical properties of scintillating materials

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Several important scintillator materials, such as cadmium and zinc tungstates ($CdWO_4$and $ZnWO_4$) and yttrium orthoaluminate $YAlO_3$, were studied in detail using the plane wave based first-principles calculations. The structural, electronic and optical properties of these materials were calculated [1, 2]. The theoretical results were in good agreement with the experimental X-ray photoelectron spectra and reflectivity data available in the literature. Differences in the Cd 4d and Zn 3d states were analyzed to explain the optical properties of $CdWO_4$and $ZnWO_4$. Variations in the electron density distributions due to crystallographically non-equivalent oxygen positions were revealed. The influence of elevated hydrostatic pressure on the structural, electronic and elastic properties was studied theoretically [3]. Special attention was paid to the calculations of the structural and electronic properties of doped materials, containing impurity ions with a single electron in the unfilled shell, such as Ce^{3+} and Ti^{3+} [4, 5], which allowed to see the impurity states in the host's band gap, identify the ground states of impurity ions with respect to the top of the host material valence band and model the microscopic crystal field effects.

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Bi-localized recombination

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Luminescence dosimetry is based on two long lasting luminescence phenomena - thermoluminescence (TL) and optically stimulated luminescence (OSL). Many dielectric materials exhibit both TL and OSL properties [1]. During irradiation traps and recombination centers are filled with electrons and holes. There are strong arguments that traps (T) and recombination centers (RC) form T-RC pairs [2]. The localized and semi-localized mechanism allows to explain many features observed in TL and OSL characteristics of radiation detectors [3,4].

Using simple electrostatic arguments it is easy to show that the system of T-RC pairs is more energetically preferred than the system of separate traps and recombination centers. On the other hand, when the number of T-RC pairs increases, it is clear that the same electrostatic arguments justify formation of small clusters with equal number of charged traps and charged RCs. The smallest cluster of this type consists of two T-RC pairs. This is the case of bi-localized system of traps.

The paper presents kinetic equations for TL and OSL luminescence related to bi-localized recombination. Analytical formulation allows to analyze in detail all elemental processes leading to TL and OSL. The properties of bi-localized transitions (BLT) are very interesting. In particular, the BLT TL glow curve usually consists of two nearly first order peaks. However, the estimated activation energies may significantly differ from the real values. Therefore the classical first-order approach should be modified. Appropriate analysis of the experimental data may help to identify the BLT case of radiative recombination.

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Energy transfer processes upon thermal quenching of self-trapped excitons in $CdWO_4$:Sm crystals

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Tungstates of alkaline earth, transition and post-transition metals (e.g., $CaWO_4$, $CdWO_4$, $PbWO_4$) are widely used as scintillator materials in security, medicine and particle physics devices. Their operation in these applications is based on the radiative decay of self-trapped excitons (STEs) localized at oxyanion complexes. Hot charge carriers created by ionizing radiation are quickly thermalized, forming STEs due to a large phonon energy and strong electron-phonon interaction, and do not transfer energy efficiently to defects and impurities in these systems. In turn, the energy transfer from STEs to various types of luminescence centres has been studied insufficiently. The energy transfer has been related to thermal quenching of STE emission, however, it is not known whether it is the result of thermal ionization, non-radiative recombination or energy transport due to a hopping diffusion. In the present work, we present the results of the studies on the STEs capability of transferring energy to impurity ions in $CdWO_4$:Sm by the methods of luminescence and EPR spectroscopy.

The XRF analysis of single crystals of $CdWO_4$:Sm, grown at the Institute for Scintillating Materials, Kharkiv, Ukraine, showed that beside 1×10^{-2} m% of Sm, the samples contained also 0.13 m% Na, 3.5×10^{-2} m% Cl, and 2×10^{-2} m% Cu. The dependence of STE and Sm^{3+} time-resolved luminescence and thermally stimulated luminescence on temperature was investigated upon irradiation by UV-VUV light from laboratory setups or synchrotron radiation sources in the temperature range 80 - 650 K. The nature of the trapped charge carriers was studied by EPR after selective irradiation by UV light. A special attention was paid to the energy regions of intra-centre impurity excitation, direct exciton creation in the Urbach tail and electron-hole continuum.

It is shown that while the intensity of the Sm^{3+} emission remains practically unchanged under the intra-centre excitation in the whole temperature range studied, it undergoes a remarkable evolution with temperature under excitation in the excitonic and fundamental absorption regions. Namely, it remains modest due to a competitive process of STE formation at low temperatures, grows drastically in the region of thermal quenching of the STE emission (250-400 K) and thereafter is thermally quenched in the region of 400-650 K. The STE emission quenching is ascribed to a hopping diffusion of STEs and formation of Sm^{3+} trapped excitons. The quenching of Sm^{3+} emission is related to the ionization of Sm^{3+} trapped excitons. The role of charge carriers trapped at accompanying impurities is clarified by the EPR studies. A detailed analysis of the mechanism of energy transfer by STEs will be presented.

Thermoluminescence of LuAG:Ce,Mg epitaxial films

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LuAG:Ce ($Lu_3Al_5O_{12}$:Ce) garnet is a scintillator with high detection efficiency, good light yield (up to 20 ph/keV), short decay time of the fast scintillation component (around 60 ns), long emission wavelength (at approximately 530 nm) and high chemical stability. Unfortunately, LuAG:Ce single crystals exhibit an intense slow decay component caused mainly by electrons tunneling from a trap related to the Lu_{Al} antisite defect to Ce^{3+} luminescence center. Such trapping is evidenced by an intense thermoluminescence (TSL) signal [1].

Since antisite defects are produced mainly due to high growth temperature, they are present in lower concentration in LuAG:Ce epitaxial films (growth temperature $\geq$ 1000°C). Consequently, a less intense TSL signal is obtained in these films [1]. Moreover, the slow scintillation component is reduced, though not eliminated. Recently, Mg-codoping has been successfully adopted for LuAG:Ce single crystals and ceramics [2]. Mg^{2+} ions stabilizes Ce^{4+} ions, which capture free electrons from the conduction band. Thus, the probability of electron capture by a trap is significantly reduced. Slow scintillation component is progressively reduced by increasing Mg concentration. At the optimal Mg concentration (500 ppm), light yield is higher. This effect has been observed in single crystals, ceramics, and epitaxial films [3].

In this contribution, several TSL measurement of films with different Mg concentration (0-3000 ppm) will be presented, both spectrally unresolved (30°C - 450°C), and spectrally resolved (10 - 279 K and 30°C - 450°C). All data are strongly correlated to Mg concentration and further improve our knowledge on LuAG:Ce,Mg scintillation mechanism.

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TSL and OSL kinetics with impeded transport of charge carriers

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Optically stimulated luminescence (OSL) and thermostimulated luminescence (TL, TSL) form the background of the readout techniques used in luminescent dosimetry. The OSL readout is more convenient but not always applicable. We discuss the nature of the long decay times at OSL readout.

A simple model was developed to describe the TSL peaks in $Li_2B_4O_7$:Mn and $Li_2B_4O_7$:Be,Mn [1]. The impeded transport of carriers towards recombination centres is treated using the recombination coefficient written in the Arrhenius form: W_R=$W_{R0}\cdot$exp(-E_R/KT). We insert an additional term to describe the optical emptying of traps. The analysis of the experimental data demonstrates that a large activation barrier E_R for recombination causes a long decay time and low OSL signal, no matter how large is the barrier for the charge carrier release from traps. Only the TL maxima with pure first-order kinetics are easily cleared with the OSL. The presence of a distinct E_R is characteristic for the hole transport in complex oxides. If the TSL and OSL occur with the electron transfer, no direct barrier is usually present. But re-trapping impedes the readout [2] and can be described with an efficient E_R as well. In most cases using elevated temperatures is inefficient to improve the OSL readout, with only minor acceleration effects possible for E_R as low as 0.1 eV. When the charge carrier transport is impeded, the only way to increase the OSL signal is to use highly intensive stimulating light.

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Correlation between TSL and temperature behavior of the X-ray excited luminescence below room temperature in cerium doped garnets

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Multicomponent garnets are promising materials to use as LED phosphors or scintillators for radiation detectors due to the outstanding luminescent properties they show when activated by cerium. In most applications it is desired that the parameters of the phosphor or scintillator do not change in the range of operating temperatures.

Above a certain temperature light output of the scintillator starts to decrease. This process is usually called positive temperature quenching. It has been shown that in case of Ce doped multicomponent garnets the main process responsible for luminescence quenching is a thermally activated excitation of an electron from excited 5d states of Ce^{3+} [1]. A few other processes are known that can influence the temperature quenching, such as thermally activated concentration quenching [2] or thermally activated transfer of an electron from excited Ce^{3+} to the nearby defect [3].

For some compositions the decrease in the luminescence intensity can be observed at low temperatures and is usually referred to as negative temperature quenching. Authors of [4] in case of Gd containing garnets connected such behavior with the temperature dependence of $Gd^{3+} \rightarrow Ce^{3+}$ energy transfer efficiency. On the other hand it was shown in [5] that the luminescence of YAG:Ce stimulated by gamma irradiation also decreases upon cooling. In this work negative temperature quenching have been studied for Ce doped multicomponent garnets of various compositions and sintering conditions. Correlation between thermally stimulated luminescence glow curves and temperature dependence of the X-ray excited luminescence intensity has been found in the range where the negative temperature quenching takes place.

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Thermal effects on stimulated luminescence of $SrAl_2O_4$:Eu^{2+},Dy^{3+} and $Sr_4Al_{14}O_{25}$:Eu^{2+}, Dy^{3+}: Thermal assistance and thermal quenching

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Stimulated luminescence measured at any temperature is affected, to different extent, by thermal assistance and thermal quenching. In the case of persistent luminescence phosphors, these effects are difficult to quantify because the luminescence often ensues with very high efficiency. This masks any little additional component due to thermal assistance and any loss due to non-radiative transitions. The problem is also exacerbated by the fact typical glow-curve in these examples are dominated by an apparently-single peak which is in fact a combination of closely-spaced peaks [1-2]. We report the study of thermal assistance and thermal quenching in $SrAl_2O_4$:Eu^{2+}, Dy^{3+} and $Sr_4Al_{14}O_{25}$:Eu^{2+},Dy^{3+}undertaken using continuous optical stimulation at 870 nm with the emitted luminescence detected in the transmission band 250 - 600 nm. Samples were excited by beta irradiation. Thermal quenching was studied principally by using the influence of heating rate on thermoluminescence intensity. Activation energies will be reported and models to explain the results discussed.

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Emergency Luminescent Dosimetry using modern smartphones

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Hundreds of thousands of people may be exposed to unknown radiation doses in case of a nuclear accident (like the Chornobyl Nuclear Power Plant accident in 1986 in Ukraine) or a nuclear terrorist attack. The levels of radiation doses obtained by different persons could be quite different; therefore, it is necessary to triage people according to obtained doses in order to separate the "worried-well" from those who need in urgent medical assistance. Because general population usually do not carry dosimeters, some fortuitous materials should be used to estimate emergency doses. These materials should be carried by people during emergency exposure either in or close to their bodies and should keep information about emergency doses for at least several days after exposure.

Two main approaches are currently proposed [1] for emergency dosimetry, namely biodosimetry, which deals with damage and alterations produced by radiation in cells and tissues, and physical dosimetry, which studies radiation-induced markers in both biologically-derived (nails, teeth) and nonliving materials using physical methods (thermo- and optically-stimulated luminescence (TL and OSL), electron paramagnetic resonance (EPR)).

Many different materials have been proposed and tested as emergency dosimeters with TL, OSL and EPR techniques. Modern smartphones are of a special interest in this regard due to their wide occurrence and location (while in use) near to the person's body, which makes it quite easy to convert the dose of a phone to the dose to an individual. Such devices include a variety of components (among others, surface mount resistors (SMRs), integrated circuits (ICs), display and protective glasses (PGs)), which could store information about interaction with radiation and may be used for emergency dose reconstruction [2-3].

In the present study, up-to-date results obtained for SMRs, ICs and PGs from smartphones tested with luminescence techniques (both TL and OSL) are reported. The following dosimetric properties were tested: variability of both radiation-induced and possible background signals (RIS and BG); dose response; values of minimum detectable dose; stability of the corresponding RIS with time after irradiation for different storage conditions. Special attention was paid to possible dosimetry with PGs, because such glasses may potentially be removed from a phone without destruction of the latter.

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Investigation of luminescence signal properties from common salts (NaCl) and salted snacks for radiation accident dosimetry

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Radiation accidental exposures as in case of nuclear accident or malevolent attack might induce severe health effects. Non-invasive and sufficiently accurate retrospective dosimetry methods are thus necessary for determining the dose received by the victims and then select an appropriate medical treatment. Materials found on the victims or in their vicinity could be used as fortuitous retrospective dosimeters. Among those, previous studies [1-7] using thermoluminescence (TL) and optically stimulated luminescence (OSL) have shown that NaCl presents interesting dosimetric properties for this application.

In this work, luminescence signal properties (sensitivity, dose response, signal stability…) from common salts and salted snacks marketed in France will be presented. In particular, a focus will be made on fading aspects as these products are sometimes not stored in light-tight packaging and the luminescence signals may be affected. Results of dose recovery tests performed under realistic conditions will be discussed.

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Friday, 14 September 2018, 12:15-12:30 O61-Fri

Observations regarding the Build-Up Effect in Radiophotoluminescence of Silver-Doped Phosphate Glasses

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Radiophotoluminescence (RPL) from silver-doped phosphate glasses is a well-known and reliable technique for dosimetry [1,2]. Irradiation induces electrons and holes which subsequently change the valence state of Ag^+ ions, converting them to Ag^0 atoms and Ag^{2+} ions by electron and hole trapping, respectively. Clustering of the Ag species is also reported in the literature, forming centers of the type , where *n* and *m* are integers [3-5]. The Ag^0 and Ag^{2+} sites are believed to act as emissions centers when stimulated with UV light following irradiation [e.g. 6,7]. The intensity of the light so emitted (i.e. the RPL intensity) is found to be proportional to the dose of radiation received, up to certain dose limits.

A particular phenomenon of RPL from phosphate glass dosimeters is the so-called ‘build-up’ effect following irradiation wherein the RPL signal continues to grow over a period of hours until it reaches a maximum. Although potential mechanisms for the build-up effect have been discussed in the literature, no conclusive evidence has yet been forwarded to explain the detailed causes. In this paper we report experiments on GD301 Ag-doped phosphate glasses from Chiyoda Technol Corporation, Japan. We discuss some new observations regarding the build-up phenomenon using RPL, photoluminescence and optical absorption. These observations include the variation of the phenomenon, when monitored *after* radiation exposure, as a function of dose, irradiation time, temperature and ultra-violet light illumination. We also demonstrate some results wherein the build-up phenomenon was followed *during* the exposure. Any model proposed for build-up must be able to accommodate the observed effects.

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Fabrication and performance optimization of Mg^{2+} codoped $Ce:Lu_3Al_5O_{12}$ scintillation ceramics

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$Ce:Lu_3Al_5O_{12}$, (Ce:LuAG) is a promising scintillation material for hard X/ϒ-ray detection due to its high density (6.7 g/m^3), fast response (60-80 ns) and high light yield. By comparison, LuAG ceramics have advantages in uniformly doping, low price and lower fabrication temperature, which may bring a superior scintillation properties because of fewer anti-site defects.

In the past years, the divalent alkali earth ions such as Ca^{2+}, Mg^{2+} co-doping has been employed to improve the scintillation performance of some Ce doped inorganic scintillator materials. Directed by this strategy, we fabricated $Ce:Lu_3Al_5O_{12}$ optical ceramics co-doped with Mg^{2+} by the solid-state reaction method. We found that Mg^{2+} co-dopants in ceramics drive the partial conversion of Ce^{3+} to Ce^{4+}, and the positive role of Ce^{4+} ions in the scintillation mechanism was discussed [1]. Furthermore, we investigated the effect of Mg^{2+} co-doping concentrations varying from 0.1 to 0.6 at%. The optimized Mg^{2+} doping content was 0.2 0.3 at%, and the corresponding ceramics displayed a more intense and faster scintillation response than commercially isostructural single crystals [2]. Then, the influence of air annealing on the microstructure and scintillation properties of Ce,Mg:LuAG scintillation ceramics was further investigated. We found that an Al_2O_3 secondary phase emerged after the high temperature annealing. A clear and positive trend of scintillation efficiency (both XEL and LY) with increasing annealing temperatures was obtained and further explained as the elimination of oxygen vacancies and an increasing concentration of the stable Ce^{4+} center. Meanwhile, the influence of Ce concentration on the optical properties was also studied [3]. The correlations among steady state scintillation efficiency, light yield, thermoluminescence and Ce^{3+} concentration were found and discussed.

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TL measurements of in-vitro and in-vivo aged feldspathic porcelain

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Radiation accidents led to the birth of a new area, the accidental dosimetry. Thermoluminescence (TL) is a basic application tool in radiation dosimetry. Its main application is οn the determination of absorbed dose due to radiation events, over and above the normal background radiation. Several materials have been studied as potential accidental dosimeters [1]. This study is focused on materials which can be found assembled in a person, like biomaterials which are widely used in surgical and dentistry applications [2].

Feldspathic porcelain (FP) has been widely used in dentistry and is the most applied material as veneer layer in metal-ceramic restorations. The aim of the present work is to prove this material as a personal dosimeter. For this purpose, freshly prepared samples and in-vitro aged were examined, and the measurements were also applied in samples collected from patients. The majority of relevant scientific works are referred only to laboratory prepared samples [3]. It is a unique experiment that aims to compare in-vitro and in-vivo aged samples and their dosimetric properties. Additionally, characterization analysis (FTIR, XRD, SEM-EDS) was applied to every step of the aging, in order to examine if TL can be established as a characterization method of the aging progress of FP.

The preliminary thermoluminescence measurements on FP show that the glow curve is consisted basically of two glow peaks. The first one is a low temperature peak around 100 °C and the other one is a high temperature peak at 245 °C. The high temperature peak is suitable for dosimetric applications, while the low temperature peak shows characteristics which seem to be suitable for estimating the time elapsed from the end of irradiation (medical irradiation or accident with ionizing irradiation).

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